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SATELLITE SERVICES SYSTEM PROGRAM PLAN

prepared by

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FOREWORD

This study was conducted between September 1984 and July 1985 for the Engineering Directorate, Gordon Rysavy - Technical Monitor, of the NASA Lyndon B. Johnson Space Center. The purpose of this study has been to develop and evaluate from the customer's perspective a program plan for the on-orbit servicing of spacecraft. This information will be used by NASA planners to assist in the development of a NASA program plan in this area. Results from this study were presented at NASA/JSC on June 21, 1985.

Stephen J. Hoffman served as Principal Investigator for this effort with significant contributions provided by Deanna Limperes, John Niehoff, Timothy O'Donoghue, Daniel Spadoni, and William Wells of SAIC along with Mike Bay and A. Lew Sprott of Fairchild Space Company.

ACRONYMS AND ABBREVIATIONS

AXAF	ADVANCED X-RAY ASTROPHYSICS FACILITY	LOS	LAND OBSERVATION SATELLITE
BAPS	BERTHING AND POSITIONING SYSTEM	MMU	MANNED MANEUVERING UNIT
DMSP	DEFENSE METEOROLOGICAL SATELLITE PROGRAM	MPSS	MISSION PECULIAR EQUIPMENT SUPPORT STRUCTURE
EMU	EXTRAVEHICULAR MOBILITY UNIT	MPS	MATERIALS PROCESSING SATELLITE
ERBS	EARTH RADIATION BUDGET SATELLITE	NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
ERS	EARTH RESOURCES SATELLITE	NOAA	NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMIN.
EVA	EXTRAVEHICULAR ACTIVITY	OMV	ORBITAL MANEUVERING SYSTEM
FSS	FLIGHT SUPPORT SYSTEM	ORS	ORBITAL REFUELING SYSTEM
GAS	GETAWAY SPECIAL	OTV	ORBIT TRANSFER VEHICLE
GEO	GEOSYNCHRONOUS EARTH ORBIT	PIP	PAYLOAD INTERFACE PANEL
GRM	GEOPOTENTIAL RESEARCH MISSION	RMS	REMOTE MANIPULATOR SYSTEM
GRO	GAMMA RAY OBSERVATORY	RSSS	RECONFIGURABLE SATELLITE SERVICING SYSTEM
HPA	HOLDING AND POSITIONING AID	SIRTF	SPACE INFRARED TELESCOPE FACILITY
HST	HUBBLE SPACE TELESCOPE	SMM	SOLAR MAXIMUM MISSION
IOC	INITIAL OPERATIONAL CAPABILITY	SPOT	SYSTEM PROBATOIRE d'OBSERVATION de 1a TERRE
JEA	JOINT ENDEAVOR AGREEMENT	ST	(HUBBLE) SPACE TELESCOPE
JSC	JOHNSON SPACE CENTER	STS	SPACE TRANSPORTATION SYSTEM
KSC	KENNEDY SPACE CENTER	TPAD	TRUNNION PIN ATTACHMENT DEVICE
LCF	LEASECRAFT/FAIRCHILD	UARS	UPPER ATMOSPHERE RESEARCH SATELLITE
LEO	LOW EARTH ORBIT		

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STUDY SYNOPSIS

In April of 1984 the Solar Maximum Mission spacecraft became the first orbiting vehicle to be visited by the Space Shuttle for the purpose of on-orbit servicing. Since that time the errant Westar and Palapa have been recovered and an attempt has been made to activate the dormant Leasat vehicle all from the Space Shuttle. Several experiments and demonstrations have also been carried out on board the Shuttle for other servicing activities such as liquid propellant transfer. And plans are continuing for the on-orbit maintenance of major NASA facilities such as the Hubble Space Telescope and the Gamma Ray Observatory.

The rapidity with which the Space Shuttle has carried out these and other missions has lead to a growing realization among a diverse group of institutions, both governmental and private, both domestic and foreign, that near Earth space has indeed become routinely accessible. In addition these demonstrations by the Space Shuttle of rendezvous, maintenance, repair and/or retrieval have also convinced these institutions that assets of considerable value can be safely located and maintained in orbit. The questions being raised, then, are not "whether" but "how" and "by whom" will these assets be serviced.

The purpose of this study is to determine the potential for servicing all of these diverse assets from the Space Shuttle Orbiter and to assess NASA's role as the catalyst in bringing about routine on-orbit servicing. Specifically this study seeks to determine what requirements, in terms of both funds and time, are needed to make the Shuttle Orbiter not only a transporter of spacecraft but a servicing vehicle for those spacecraft as well.

The scope of this effort is to focus on the near term development of a generic servicing capability. To make this capability truly generic and attractive requires that the customer's point of view be taken and transformed into a widely usable set of hardware. And to maintain a near term advent of this capability requires that a minimal reliance be made on advanced technology.

With this background and scope, this study will proceed through three general phases to arrive at the desired program costs and schedule. The first step will be to determine the servicing requirements of the user community. This will provide the basis for the second phase which is to develop hardware concepts to meet these needs. Finally, a cost estimate will be made for each of the new hardware concepts and a phased hardware development plan will be established for the acquisition of these items based on the inputs obtained from the user community.

STUDY SYNOPSIS

- STUDY OBJECTIVE
 - TO DETERMINE THE POTENTIAL FOR SATELLITE SERVICING FROM THE SHUTTLE ORBITER FOR ALL USERS AND ASSESS NASA'S ROLE AS THE CATALYST TO OPERATIONAL SERVICING

- SCOPE OF EFFORT
 - FOCUS ON NEAR TERM SERVICING CAPABILITY
 - REPRESENT USERS' POINT OF VIEW
 - MINIMIZE RELIANCE ON ADVANCED TECHNOLOGY WHICH COULD DELAY APPLICATION

- STUDY APPROACH
 - DETERMINE USER COMMUNITY REQUIREMENTS
 - DEVELOP NEW HARDWARE CONCEPTS WHERE NECESSARY TO ASSURE COMPLETE USER ACCOMMODATION
 - FORMULATE A PHASED HARDWARE DEVELOPMENT PLAN WITH COST ESTIMATES

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STUDY CONSTRAINTS

In keeping with the objective and scope of the study, several constraints were established at the outset of this effort. The first of these is to focus on the potential servicing missions in the 1986 through 1993 (i.e. Space Station IOC) time frame. Secondly, the candidate servicing missions and hardware concepts should not rely on developments in other programs. This precluded any assistance in the servicing mission from the Orbital Maneuvering Vehicle (OMV), an orbit transfer vehicle (OTV), or the Space Station. This in effect determines a minimum capability needed for on-orbit servicing and sets the stage for expanded capability when these other systems become available.

STUDY CONSTRAINTS

- FOCUS EFFORT ON SERVICING WHICH CAN BE DONE FROM STS IN NEAR TERM
 - 1986 THROUGH 1993 TIME FRAME

- DO NOT RELY ON DEVELOPMENTS IN OTHER PROGRAMS
 - NO OMV, OTV, OR SPACE STATION
 - DETERMINE MINIMUM CAPABILITY NEEDED

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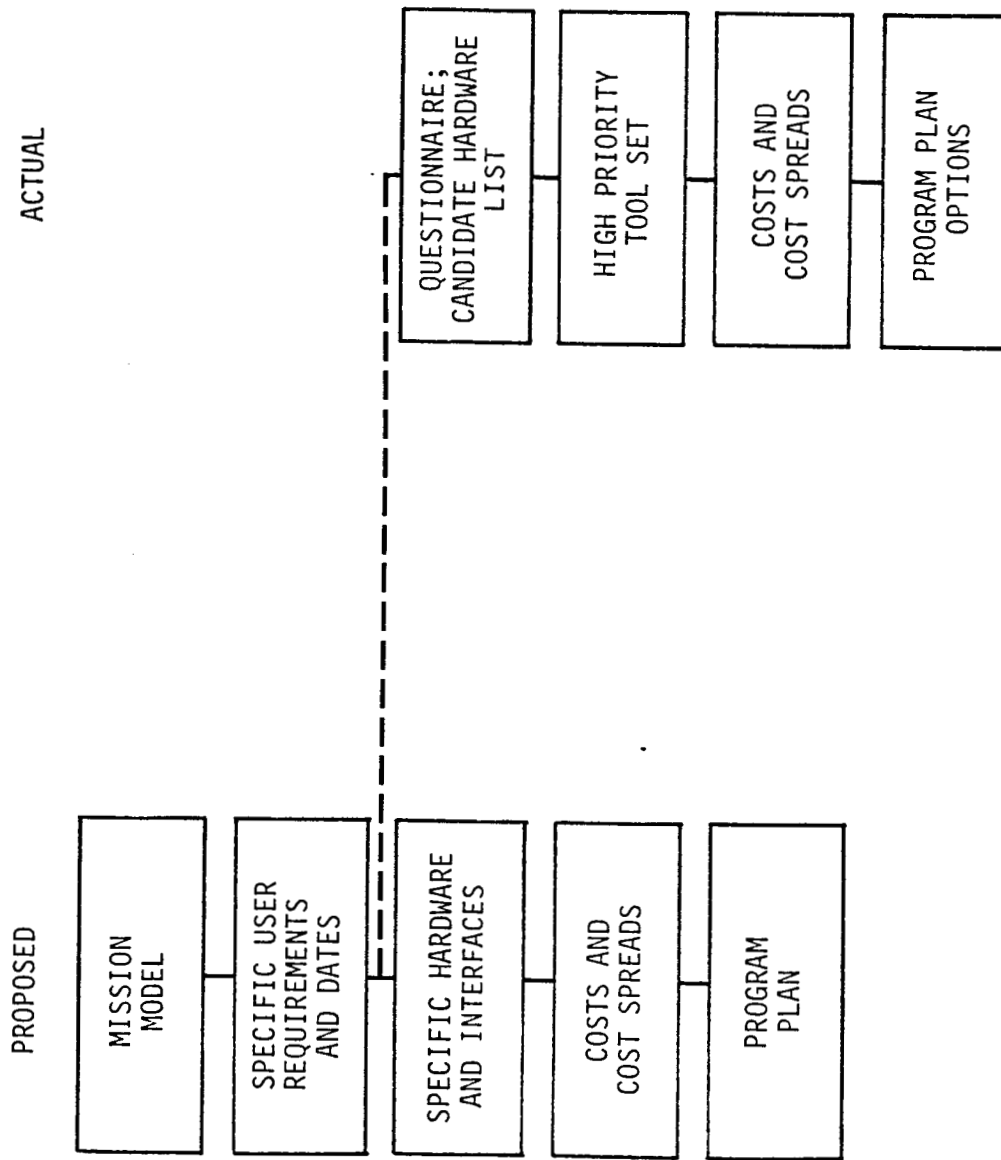
STUDY PROCESS

As originally proposed, this study was divided into five specific tasks each with a well defined end product. The first of these tasks would ascertain what missions would be flown in the time period of interest. These missions would be divided into those which would definitely require servicing, those which would be serviced on a contingency basis or could be designed to take advantage of servicing, and finally those which, for whatever reason, were not servicable. The second task would take the first two groups of missions and, based on published information or contact with the user, determine specific user requirements and servicing dates. The third task would match hardware to these user requirements and identify all interfaces between the user and the servicing equipment. The fourth task would estimate the cost and three year cost spreads for any new hardware items required to meet user needs. Finally, the servicing dates provided by the users would be utilized to develop a satellite servicing program plan for the development and acquisition of all hardware elements.

When put into action, the first and second tasks were implemented as planned. However, it was determined in the second task that, with the exception of a few missions, specific servicing requirements were not known. Many potential customers were still analyzing their options and assumed that they would adapt to hardware already in existence. These potential customers were generally reluctant to level specific servicing requirements on NASA due to uncertainty in the operational date for that hardware and potential development charges assessed by NASA on the first customer.

To circumvent this situation and still obtain user community inputs, a "what if" scenario was devised and a questionnaire prepared for distribution to the potential users. This questionnaire, the actual third task in this study, combined a list of existing and new hardware concepts which the users were asked to rate for acceptability to their servicing needs. Results from this questionnaire will be presented in subsequent sections of this report. These results allowed a high priority tool set to be drawn from the tool list (actual Task 4) and costed as originally planned. Since no firm requirements were generated as part of this questionnaire, the last task prepared various program plan options based on assumptions generated from the questionnaire.

STUDY PROCESS



KEY FINDINGS AND RESULTS

Before presenting any details of the study tasks, a set of key findings and results from all of the tasks will be discussed to both help introduce and explain the direction taken by each task.

Between 1986 and 1993, 63 missions were identified from NASA, NOAA, DoD, U.S. commercial and foreign institutions which could be reached by, or could potentially fly down to, the Space Shuttle Orbiter. Thirty-three of these missions were identified as potentially serviceable: 12 on a regular or scheduled basis, 21 on a contingency basis. If all of these missions are flown at their presently scheduled times, there appears to be sufficient traffic for up to 20 servicing sorties per year in 1993. Since many of these vehicles are in the early design phase, precise servicing requirements and interfaces are not known for these vehicles. As servicing hardware and procedures are developed for other missions, the design of these vehicles will evolve to take advantage of these developments. However, many potential customers remain undecided regarding the degree to which their spacecraft should be serviced on-orbit.

KEY FINDINGS AND RESULTS

- 33 VEHICLES POTENTIALLY SERVICEABLE
 - 12 ON A REGULAR BASIS
 - 21 ON A CONTINGENCY BASIS
- APPEARS TO BE SUFFICIENT TRAFFIC TO SUPPORT UP TO 20 SERVICING SORTIES PER YEAR
- PRECISE SERVICING REQUIREMENTS AND INTERFACES NOT KNOWN IN MAJORITY OF CASES
- MANY POTENTIAL CUSTOMERS REMAIN UNDECIDED REGARDING ON-ORBIT SERVICING

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KEY FINDINGS AND RESULTS (continued)

The reason for this indecision can be traced back to several key features of NASA policy. First, there is no NASA policy statement in existence regarding the routine (operational) on-orbit servicing for non-NASA vehicles. The non-NASA community is thus uncertain as to the degree of commitment NASA will make in the long term for the on-orbit servicing of their vehicles. Secondly, the user community has indicated, through the questionnaire mentioned previously, that a pricing policy for on-orbit servicing is of equal or greater importance than specific knowledge of hardware capabilities or interfaces. This pricing policy is critical for the determination of the level of servicing and no such policy currently exists. As long as the formulation of this pricing policy is deferred, customers will try to minimize their uncertainty and risk by opting for non-serviceable or minimally serviceable spacecraft. Finally, most non-NASA users are waiting to see what hardware NASA will design, develop and acquire for servicing. These users will tend not to level requirements on NASA for fear that NASA will burden them with the development cost as the first user. These customers feel that they have sufficiently clever engineers to make the best use of existing hardware or to design and develop hardware for their specific use.

KEY FINDINGS AND RESULTS (CONTINUED)

- NO NASA POLICY REGARDING ROUTINE (OPERATIONAL) ON-ORBIT SERVICING FOR NON-NASA PAYLOADS EXISTS
- PRICING POLICY IS OF EQUAL OR GREATER IMPORTANCE THAN PRECISE KNOWLEDGE OF HARDWARE INTERFACES AND CAPABILITIES
- AS LONG AS PRICING POLICY IS DEFERRED, CUSTOMERS WILL TEND TO OPT FOR NON-SERVICEABLE OR MINIMALLY SERVICEABLE SPACECRAFT
- NON-NASA USERS WAITING TO SEE WHAT NASA WILL DESIGN, DEVELOP AND ACQUIRE AS GENERIC HARDWARE
 - USERS WILL NOT LEVEL REQUIREMENTS ON NASA
 - USERS WILL REACT TO HARDWARE ALREADY AVAILABLE

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KEY FINDINGS AND RESULTS (continued)

The user community thus feels that the next move is up to NASA to break the current "Catch-22" situation (NASA waiting for customers to specify requirements so that hardware can be built; customers waiting for hardware and pricing policy so that the most cost effective vehicle can be designed). If the customers perceive that NASA will not take the next step, then they will opt for non-serviceable spacecraft or will design and build their own unique servicing hardware. From NASA's perspective, this latter situation could mean a proliferation of hardware interfaces and servicing procedures as each new vehicle is developed.

KEY FINDINGS AND RESULTS (CONTINUED)

- NEXT MOVE IS NASA'S; THE RIGHT RESPONSE WILL BREAK THE "CATCH-22" SITUATION

- IT IS IMPORTANT TO REMEMBER THAT NASA IS SELLING A SERVICE
 - IF CUSTOMERS ARE DISSATISFIED, THEY WILL DO WITHOUT OR WILL BUILD THEIR OWN HARDWARE
 - IF THE CUSTOMERS BUILD THEIR OWN HARDWARE, THERE IS A RISK OF PROLIFERATING FUNCTIONALLY SIMILAR BUT PHYSICALLY DIFFERENT HARDWARE

- NASA AND CUSTOMERS CAN WORK TOGETHER IF NASA DEFINES THE GROUND RULES (POLICY);
EXAMPLES INCLUDE:
 - CUSTOMER DEVELOPED HARDWARE LEASED TO NASA OR RENTED TO OTHER USERS
 - NASA PURCHASED HARDWARE WITH CUSTOMER LEASE-BACK OPTIONS
 - NASA DEVELOPED PROTOTYPES, CUSTOMER PURCHASED FLIGHT ARTICLES

KEY FINDINGS AND RESULTS (continued)

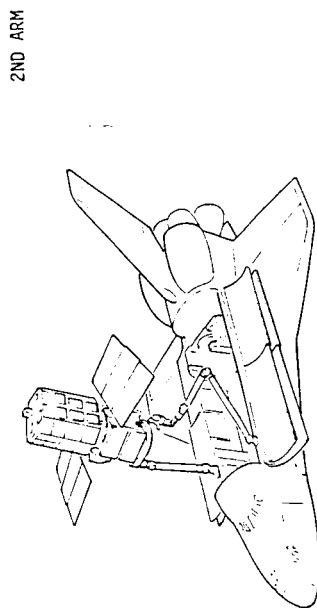
If NASA decides to offer servicing to non-NASA customers as a standard STS feature, then the user community questionnaire indicates that there are several highly desirable attributes and components which should be part of this service. The customers will expect to see identical interfaces at the STS, OMV, OTV and Space Station. A strong preference was also indicated for the following hardware items:

- (1) A payload interface panel which will allow more direct and sophisticated communication with the spacecraft being serviced by those on board the Space Shuttle. This will allow the vehicle to be monitored during servicing and checked when all servicing has been completed.
- (2) A second arm either in the form of a second RMS (preferred) or an HPA mounted on a cradle. This will allow vehicles to be serviced outside of the payload bay envelope and avoid a potential charge to reserve clearance space within the payload bay.
- (3) Remote controlled fluids coupling. This would avoid EVA time to connect and disconnect such a coupling.
- (4) A large (5000 lb minimum capacity) monopropellant tanker. Vehicles which potentially need refueling require anywhere from 2000 to 5000 lb of propellant. No missions using bipropellants or cryogenics were identified.
- (5) Large spacecraft berthing device. This device was identified for very massive vehicles (30000-40000 lb) which would be berthed to the orbiter for extended periods of time (6-8 hrs or more).

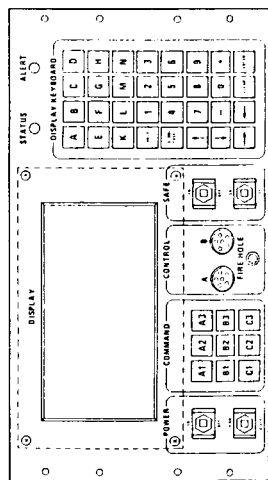
KEY FINDINGS AND RESULTS (CONTINUED)

IF NASA DECIDES TO SERVICE NON-NASA PAYLOADS:

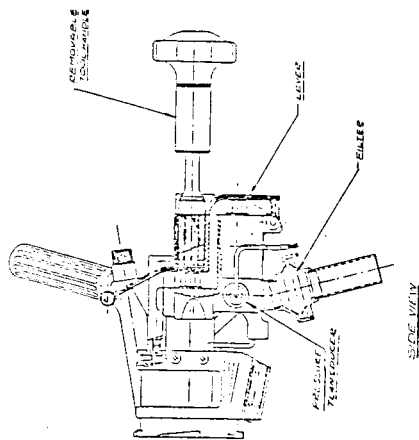
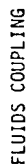
- USERS EXPECT TO SEE IDENTICAL INTERFACES AT STS, OMV, AND SPACE STATION
- HIGHLY DESIRABLE HARDWARE DEVELOPMENTS FOR NEAR TERM SERVICING



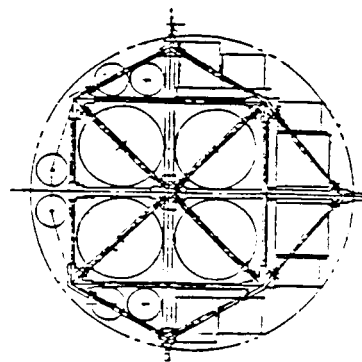
2ND ARM



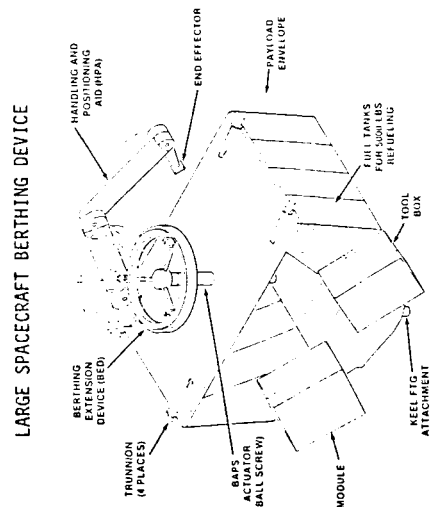
PAYLOAD INTERFACE PANEL



ALMA JOHNS



LARGE TANKER



LARGE SPACECRAFT BERTHING DEVICE

KEY FINDINGS AND RESULTS (continued)

The advantages to NASA in taking this approach will be to not only expand the uses for the Space Shuttle but also to acquire practical experience in designing and operating servicing hardware which could be used by the OMV and Space Station. This will also cultivate a sense of confidence in the servicing concept among those customers who will ultimately be based at the Space Station or will be accessible only by means of the OMV or OTV.

KEY FINDINGS AND RESULTS (CONTINUED)

- ADVANTAGES TO NASA
 - ACQUIRE EXPERIENCE IN PROCEDURES AND HARDWARE TO BE USED BY SPACE STATION, OMV AND OTV
 - CULTIVATE USER CONFIDENCE IN STS SERVICING CAPABILITIES WHICH WILL TRANSLATE INTO EARLIER SERVICABLE SPACECRAFT DESIGNS
 - THIS WILL LEAD TO FULLER UTILIZATION OF SERVICING IN THE SPACE STATION, OMV AND OTV OPERATIONAL ENVIRONMENT

KEY FINDINGS AND RESULTS (concluded)

Because of the lack of firm servicing requirements among potential customers at the present time, no single comprehensive program plan could be assembled. Rather, a set of plans were developed which bounded the range of possibilities and also examined the middle ground. At one end of the range is a "NASA-only" scenario in which only those tools which would support NASA programs would be developed (and this excludes tools currently under development for HST). This represents the situation where NASA maintains the status quo regarding non-NASA customers and thus becomes a baseline case against which other programs can be compared (Scenario 1). At the other extreme is a scenario driven by identified needs within the commercial community and assumes that spacecraft will rely on potential servicing capability to the maximum extent possible (Scenario 2, the "Fast-Start Commercialization" option). In this scenario seven of the nine identified hardware items would be operational by the end of Fiscal Year 1989 (FY89). This drives the peak year to FY88 and consumes 40 percent of the total cost during that year. A possible compromise (Scenario 3) would retain the same ultimate capability as the Fast-Start case but would stretch out the development of various hardware items to be more in line with the current NASA schedule. These three scenarios are compared on the facing page and more information concerning each plan will be presented later in this report.

KEY FINDINGS AND RESULTS (CONCLUDED)

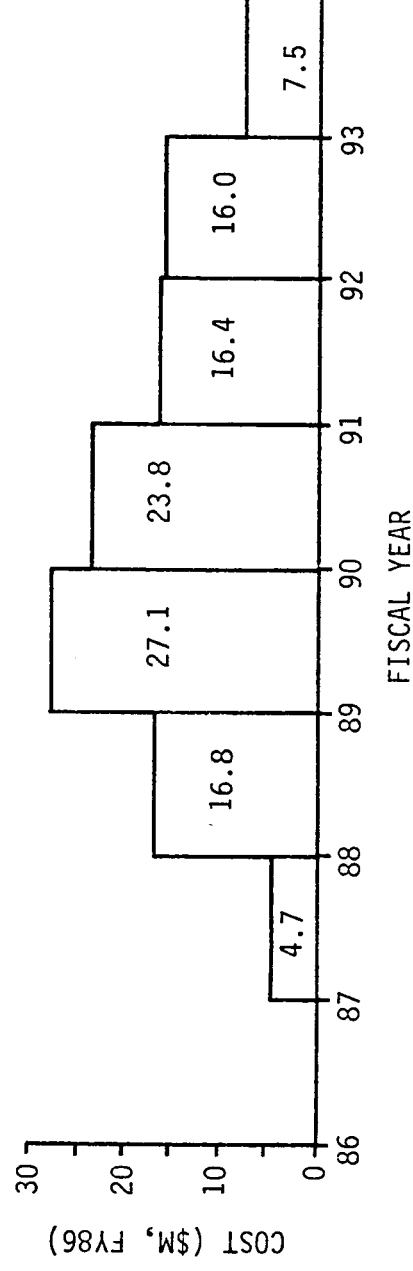
PROGRAM PLAN OPTIONS

- RANGE OF OPTIONS VARIES FROM NASA-ONLY PROGRAM TO FAST-START COMMERCIALIZATION

	NUMBER OF TOOLS	TOTAL COST (THRU FY93)	PEAK COST	PEAK YEAR
NASA-ONLY*	6	65 M (FY86)	20 M (FY86)	FY89
FAST-START*	9	125 M (FY86)	51 M (FY86)	FY88

* ASSUMES TWO FLIGHT ARTICLES

- POSSIBLE COMPROMISE - SAME ULTIMATE CAPABILITY AS FAST-START BUT SOME ITEMS DEFERRED TO LATER YEARS (ASSUMES TWO FLIGHT ARTICLES)



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MISSION MODEL

The first task in this study involved the generation of a mission model for the pre-1993 time frame. This mission model serves as the database of all current or planned missions by NASA, NOAA, DoD, commercial and foreign organizations which can potentially be reached by or fly down to the Space Shuttle Orbiter for servicing. These missions are organized into three categories, high, nominal and low, based on the degree to which the spacecraft can be serviced on-orbit. High priority missions are those specifically designed for on-orbit servicing and assume that servicing will occur on a regularly scheduled basis. Nominal priority missions are or could be designed for servicing but have no regularly scheduled servicing dates. This category also includes those missions not designed for maintenance but which could be serviced on a case by case basis if appropriate training and hardware are developed. Low priority missions are those spacecraft with a short mission lifetime or where servicing would be difficult or impossible to carry out.

Sixty-three missions were identified in the 1985-1993 time frame which met the low altitude criteria for STS servicing. Of these missions 12 were classified as high priority, and 21 as nominal priority. The remainder were classified as low priority and were dropped from further consideration. The facing page lists the high and nominal priority missions with pertinent information such as customer organization, orbit altitude, orbit inclination, accessibility by the STS and actual or proposed servicing dates. The information was obtained from published material or was generated by SAIC based on that material. The latter was necessary in those cases where official information is not available or where vehicle design and mission plans have not been finalized. Lastly, the spacecraft number (S/C #) in the left column will be used later in the tool rating table to identify which mission will use which tool.

The database generated here will now serve as input to the second task which will identify specific hardware items. In addition, this information will be used in later tasks to determine a potential sortie rate and thus the required number of flight articles.

HIGH PRIORITY

20

S/C #	CUSTOMER	ALT (KM)	INCL (DEG)	STS ACCESS.1	LAUNCH / SERVICING YEAR2									
					1979-84	85	86	87	88	89	90	91	92	93
1	NASA	600	28.5	X			ST			X		X		
2	DoD	230	97.0	X				RECON A13	X-X-X	X-X-X	X-X-X	X-X-X	X-X-X	X-X-X
3	NASA	510	28.5	X				GRO		X			X	
4	DoD	400	97.0	X				RECON B13		X			X	
5	COMM	500	28.5	X				HEAVY MPS 1	X-X-X	X-X-X	X-X-X	X-X-X	X-X-X	X-X-X
6	NASA	500	28.5	X				PROTEUS		X		X		X
7	COMM	500	28.5	X				MED/SML MPS	X-X-X	X-X-X	X-X-X	X-X-X	X-X-X	X-X-X
8	FOREIGN	500	28.5	X				EURECA F/O	X-X	X-X	X-X	X-X	X-X	X-X
9	DoD	(400)	98.0	X									X	
10	COMM	500	28.5	X									X	
11	NASA	500	28.5	X										
12	NASA	500	28.5	X										

NOMINAL PRIORITY

S/C #	CUSTOMER	ALT (KM)	INCL (DEG)	STS ACCESS. ¹	LAUNCH / SERVICING YEAR ²									
					1979-84	85	86	87	88	89	90	91	92	93
13	NASA	500	28.5	X	SIM		0							
14	NASA	610	57.0	+	ERBS		0							
15	NOAA	700	98.8	+	LANDSAT 4			0						
16	NOAA	700	98.2	+	LANDSAT 5			0						
17	DoD	230	97.0	X	RECON A	0-0-0	0-0-0							
18	DoD	400	97.0	X	RECON B		0							
19	NASA	475	57.0	X				ROSAT		0				
20	FOREIGN	500	28.5	X				EURECA	0-0					
21	FOREIGN	950	98.8	+				ERS-1		0				
22	FOREIGN	650	98.5	+				LOS-1		0				
23	FOREIGN	1050	99.0	+				MOS-2		0				
24	NASA	600	57.0	+						UARS ⁵		X		X
25	NASA	1300	65.0	+						TOPEX ⁵				X
26	FOREIGN	500	28.5	X						ROBUS ⁵	X		X	X
27	COMM	700	98.6	+						GEOSAT				
28	FOREIGN	700	98.6	+, *						RADARSAT ⁵				
29	DoD	830	98.7	*								DMSP 18		X
30	NOAA	850	98.9	*								NOAA-M		X
31	NASA	160	90.0	X									GRM	0
32	NASA	520	90.0	+, *									GRAV PB-B ⁵	X
33	FOREIGN	850	98.7	+, *									SPOT-3 ⁵	

¹ INDICATES STS ACCESSIBILITY TO VEHICLE AS CURRENTLY DESIGNED

- X ACCESSIBLE
- * ACCESSIBLE WITH DMV (IOC = 1990)
- + ACCESSIBLE IF VEHICLE LOWERS ALTITUDE WITH ONBOARD FUELLANT
- 0 INACCESSIBLE

³ PROJECTED FROM CURRENT LIFETIME LIMITING FACTORS⁵ ASSUMES MINOR REDESIGN TO ALLOW SERVICING² LAUNCH YEAR INDICATED BY MISSION NAME

- X SCHEDULED SERVICING
- 0 END OF NOMINAL MISSION
- CONTINGENCY REPAIR ON FAILURE
- CONTINGENCY REPAIR FOR EXTENDED MISSION

⁴ ASSUMES OPERATIONS SIMILAR TO LEASECRAFT

ALL DATA TAKEN OR INFERRED FROM PUBLIC SOURCES AND DOES NOT NECESSARILY REFLECT THE OFFICIAL POSITION OF THE SPONSORING ORGANIZATION.

QUESTIONNAIRE BACKGROUND

Contacts made with the user community as part of the first task indicated that in many cases on-orbit servicing considerations are in an early and dynamic phase. As a result there is a general lack of specific requirements and/or interfaces among these potential customers. In order to circumvent this problem and still obtain the desired user community inputs a questionnaire was formulated to gauge general hardware needs and priorities.

This questionnaire consisted of a set of general issue questions and a list of tools which were to be rated. Both existing and new tool concepts were to be rated to determine the general scope of user community needs. The new tool concepts contained in this list were assembled from previous studies or were generated by SAIC and Fairchild Industries based on the information already available in the mission model. Comparing these new tools with existing hardware provided a means of assessing the completeness of the tool list and development priorities.

The questionnaire was sent to individuals in both government and private organizations, generally those with experience in the design and/or construction of low Earth orbit spacecraft. All responses were voluntary and represented the opinion of the individual involved. As such, these results are not necessarily the same as those of the parent organization.

QUESTIONNAIRE BACKGROUND

- REASON FOR QUESTIONNAIRE
 - ON-ORBIT SERVICING IN DYNAMIC STATE - GENERAL LACK OF FIRM REQUIREMENTS AND/OR INTERFACES
 - NEED TO OBTAIN CUSTOMER INDICATIONS OF GENERAL HARDWARE NEEDS AND PRIORITIES
- SCOPE
 - MIXTURE OF GENERAL QUESTIONS AND RATING OF SPECIFIC TOOLS
 - RATING OF BOTH EXISTING TOOLS AND NEW CONCEPTS TO DETERMINE DEGREE OF SATISFACTION
 - COMPARISON OF NEW CONCEPTS WITH EXISTING TOOLS TO GAUGE DEVELOPMENT PRIORITIES
- LIMITATIONS
 - ALL RESPONSES VOLUNTARY
 - EXPRESSIONS OF INDIVIDUAL OPINION ONLY - NOT NECESSARILY POLICY OF PARENT ORGANIZATION
 - PARTICIPANTS GENERALLY FROM ORGANIZATIONS WITH EXPERIENCE IN DESIGN AND/OR CONSTRUCTION OF LOW EARTH ORBIT SPACECRAFT

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QUESTIONNAIRE RECIPIENTS

The facing page indicates the organizations with which the questionnaire recipients are associated. Below each organization name is a list of the type of LEO spacecraft with which that organization has had experience.

QUESTIONNAIRE RECIPIENTS

BALL AEROSPACE

- NASA
- COMMERCIAL

FAIRCHILD SPACE COMPANY

- NASA
- COMMERCIAL

GRUMMAN AEROSPACE

- NASA

LOCKHEED MISSILES AND SPACE CO.

- NASA
- DoD

MARTIN-MARIETTA CORP.

- NASA
- DoD

NASA/JSC ASTRONAUT OFFICE

RCA ASTROELECTRONICS

- COMMERCIAL
- NOAA
- DoD

ROCKWELL INTERNATIONAL

- NASA

SPAR AEROSPACE

- NASA
- ESA

TRW FEDERAL SYSTEMS DIVISION

- NASA

USAF SPACE COMMAND

- DoD

USAF SPACE DIVISION

- DoD

SAIC SPACE SCIENCES

QUESTIONNAIRE RESPONSE

The facing page lists the number of responses received from each organization. In some cases several individuals from one organization worked on the various questions and mailed back individual responses (as in the case of Ball Aerospace) or combined their results into one response. In the case of the USAF Space Division copies of the questionnaire were redistributed to several program offices and as many as 17 responses were returned to the officer in charge. At the time of this report, all responses were still under review and have not been released.

QUESTIONNAIRE RESPONSE

- COMPLETED QUESTIONNAIRES RECEIVED FROM

BALL AEROSPACE (2)

FAIRCHILD (1)

GRUMMAN (1)

LOCKHEED (0)

MARTIN-MARIETTA (1)

NASA ASTRONAUT OFFICE (1)

RCA (1)

ROCKWELL (2)

SPAR (1)

TRW (1)

USAF SPACE COMMAND (1)

USAF SPACE DIVISION (POTENTIALLY 17; WAITING FOR RELEASE AUTHORIZATION)

SAIC SPACE SCIENCES

TOOL SET BACKGROUND

The next several pages will provide details from the questionnaire responses. However, to better understand these responses, some background information must be provided.

The tool list is composed of 49 separate entries divided into six categories. These categories consist of (1) Rendezvous/Capture/Deployment, (2) Servicing Location, (3) Housekeeping Support/Vehicle Checkout, (4) Module Exchange and Repair, (5) Fluid Transfer and (6) Storage. The first digit of the tool number indicates in which category a particular tool has been placed. Thus the first tool listed in the rating results, 1.8 Remote Manipulator System, is in Category (1). One other point which should be made is that tool 4.4 Tool Box contains 28 EVA hand tools which the recipients were asked to rate as a whole. This was done as a convenience and is not meant to indicate that all 28 tools would necessarily be taken on a servicing mission. If the recipient found a particular EVA tool unacceptable this was noted separately from the overall rating.

Each entry was rated on a scale of 1 (lowest) to 5 (highest) in three different categories, namely (1) importance to servicing (2) frequency of use and (3) quality as a solution to a servicing task. An average rating, emphasizing the quality of the tool was obtained by using the formula

$$\frac{(\text{Cat. 1 Rating}) + (\text{Cat. 2 Rating}) + 2 * (\text{Cat. 3 Rating})}{4}$$

The recipients were also asked to indicate, in the case of a new or modified tool, when a commitment must be made to build that tool so that it can be incorporated into a vehicle design. They were then asked to indicate, for all tools, when that tool will first be used and by what spacecraft.

TOOL SET BACKGROUND

- TOOLS CHARACTERIZED BY SIX DESCRIPTORS
 - RENDEZVOUS/CAPTURE/DEPLOYMENT
 - SERVICING LOCATION
 - HOUSEKEEPING SUPPORT/VEHICLE CHECKOUT
 - MODULE EXCHANGE AND REPAIR
 - FLUID TRANSFER
 - STORAGE
- 49 TOOL ENTRIES
- INDIVIDUALS ASKED TO
 - RATE TOOLS IN THREE CATEGORIES: (1) IMPORTANCE TO SERVICING,
(2) FREQUENCY OF USE, (3) QUALITY AS A SOLUTION TO SERVICING
PROBLEMS
 - INDICATE REQUIRED NASA COMMITMENT DATE
 - INDICATE FIRST USE DATE AND SPACECRAFT

TOOL RATING RESULTS

The next three pages show the rating results for all tools contained in the questionnaire. These results have been ordered from highest to lowest based on the averaged response from all 12 questionnaires. Natural gaps occurred at the averaged rating of 3.8 and 2.7 providing a rough indication of high (rating greater than 3.8), medium (rating between 3.8 and 2.7), and low (rating below 2.7) degrees of satisfaction with these tools. The low tools were eliminated from any further investigation. The high and medium tools were evaluated further to determine which would enable servicing and the number of potential customers for these tools.

AVERAGE RATING (1-5)	TYPE	TOOL NUMBER	TOOL NAME	COMMITMENT DATE (QTR/YR)	FIRST USE DATE (QTR/YR)	NAME OF FIRST MISSION
4.7	E	1.8	REMOTE MANIPULATOR SYSTEM		2/89	LCF, 13, 6, 3, 12
4.5	E	1.9	PAYLOAD RETENTION SYSTEM		2/89	LCF, 8, 24, 29
4.5	E	3.6	CLOSED CIRCUIT TELEVISION		2/89	LCF, 1, 3
4.3	E	4.3	TOOL CADDY		4/87	13, 14, 17, LCF
4.2	E	2.5	MANIPULATOR FOOT RESTRAINT		2/89	LCF, 6, 7, 25
4.1	*	4.4	TOOL BOX	2/87	2/89	LCF, ALL
4.1	*	4.6	POWER TOOLS	2/88	2/89	LCF, ALL
4.0	*	3.5	STND. POWER/COMM. UMBILICAL INTERFACE	4/85	2/89	LCF, 1, 3, 6, 11, 24
4.0	**	5.5	REMOTE CONTROLLED FLUID UMBILICAL	4/85	2/89	LCF, 3, 24, 9, 29
3.9	**	3.4	PAYLOAD INTERFACE PANEL	4/85	2/89	LCF, 1, 3, 6, 11
3.9	E	3.8	RMS TELEVISION		2/89	LCF, 8, 17, 18
3.9	*	3.9	VIDEO TAPE RECORDER		2/89	LCF, 3, 6, 9, 28

3.7	E	1.7	MMU		2/89	LCF, 13, 15, 24, 11
3.6	E	4.5	TRASH CONTAINER		2/89	LCF, ALL
3.6	E	5.1	ORBITAL REFUELING SYSTEM		2/90	3, 6, 8, 24
3.6	**	5.2	LARGE CAPACITY ORBITAL REFUELING SYSTEM	4/85	2/89	LCF, 3, 24, 29, 9

E EXISTING

* MODIFICATION OF EXISTING EQUIPMENT OR SHORT TERM DEVELOPMENT

** NEW CONCEPT OR NEW DEVELOPMENT

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AVERAGE RATING (1-5)	TYPE	TOOL NUMBER	TOOL NAME	COMMITMENT DATE (QTR/YR)	FIRST USE DATE (QTR/YR)	NAME OF FIRST MISSION
3.6	E	6.3	PROVISIONS STOWAGE ASSEMBLY		2/89	LCF, 24, 25, 26
3.5	E	3.7	EMU TELEVISION		2/89	LCF, 1, 3, 11
3.5	**	4.1	ZERO PREBREATHE EMU	4/85	3/87	15, 16, LCF, 1, 3
3.4	E	2.2	FLIGHT SUPPORT SYSTEM		3/90	3, 11, 12
3.4	E	2.8	MINI WORK STATION		2/89	LCF, 6, 8, 11, 12
3.4	**	4.2	TEMPORARY TETHER LOOPS	2/87	2/89	LCF, 3, 11, 12, 19
3.4	**	4.7	RMS BASED POWER TOOLS	4/85	2/87	14, LCF, 24, 1, 3
3.3	**	1.1	LASER DOCKING SYSTEM	2/88	2/89	LCF, 4, 9, 11, 29
3.3	*	1.6	BERTHING AND POSITIONING SYSTEM		88-89	5
3.3	**	2.9	REMOTE RMS CONTROLS	1/85	2/86	13, 14, 15, 16, LCF
3.3	**	5.3	BIPROPELLANT ORBITAL REFUELING SYSTEM			
3.3	**	5.4	LIQUID CRYOGEN ORBITAL REPLENISHMENT			12
3.3	**	5.6	ORBITAL GAS REPLENISHMENT SYSTEM			
3.3	E	6.2	FSS LOCKER		3/89	1, 3, 11
3.2	*	1.3	PORTABLE GRAPPLE FIXTURE	2/87	2/89	LCF, 5, 10, 24, 32
3.2	*	2.6	PORTABLE FOOT RESTRAINT		2/89	LCF, 26, 29
3.2	**	3.2	PASSIVE THERMAL CONTROL	2/85	4/87	15, 16, LCF, 24

E EXISTING

* MODIFICATION OF EXISTING EQUIPMENT OR SHORT TERM DEVELOPMENT

** NEW CONCEPT OR NEW DEVELOPMENT

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AVERAGE RATING (1-5)	TYPE	TOOL NUMBER	TOOL NAME	COMMITMENT DATE (QTR/YR)	FIRST USE DATE (QTR/YR)	NAME OF FIRST MISSION
3.2	**	4.9	HANDHELD INFRARED HEATER	4/86	2/88	2,LCF,4,9,29
3.2	E	6.1	CARGO BAY STOWAGE ASSEMBLY		3/88	2,LCF,4,9
3.1	E	1.2	BINOCULARS		2/89	LCF
3.1	**	2.1	PORTABLE LIGHTING FIXTURES	2/87	2/89	LCF
3.1	**	4.10	CLEANING KIT	1/85	2/86	13,14,1,2
3.1	E	6.4	MPESS		4/88	5,11,12
3.0	E	1.5	TPAD		88-89	5,3,24,25,32
3.0	**	2.4	RSSS	4/85	2/89	LCF,29,32
3.0	*	3.1	PAYLOAD HEAT EXCHANGER	1/91	3/94	12
2.8	E	1.4	EXPANDING STING CAPTURE DEVICE			5,9,12,25
2.8	*	2.7	PORTABLE HANDHOLD PLATE ASSEMBLY	2/85	2/86	3,LCF,11,12,15
2.8	E	6.5	ADAPTIVE PAYLOAD CARRIER		4/88	5,6,3

2.6	**	3.3	PORTABLE RESISTANCE HEATER STRIPS	2/87	2/89	LCF
2.6	**	4.8	CABLE TIE KIT	2/87	2/89	LCF,1,5,7
2.5	**	2.3	ELEVATED KEEL FITTING	1/87	2/90	4,9
2.2	E	6.6	G.A.S. BEAM		4/88	5

E EXISTING

* MODIFICATION OF EXISTING EQUIPMENT OR SHORT TERM DEVELOPMENT

** NEW CONCEPT OR NEW DEVELOPMENT

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COMMENTS AND OBSERVATIONS

Examination of the rating tables indicates that several completely new hardware items have been rated very highly. Both the payload interface panel and the remote controlled fluid umbilical can be found in the high category and the large tanker is located just below the high/medium dividing line. The high rating of the fluid umbilical and the slightly modified power and communications umbilicals indicate the potential for offering a berthing ring with these three interfaces as a standard docking mechanism. The high rating of these items also indicates a desire on the part of the user community to minimize the amount of EVA time required to do what could be considered routine servicing tasks. The high rating of the payload interface panel indicates a desire for more sophisticated communication with and control over docked payloads by the on-orbit crew. This will give the crew an ability to monitor, check out and possibly correct the docked payload in real time.

Two items which were not rated very highly but for which a strong interest was expressed include a second arm and a means of docking a very large spacecraft while exchanging equally large modules. Both capabilities were included in a device called the Reconfigurable Satellite Servicing System (RSSS). This device consisted of two cradles which could be used separately or combined into a single payload when required. Since the low rating of the RSSS is probably due to this particular configuration rather than the need for such a capability, this device or its equivalent will be maintained as a high priority tool.

COMMENTS AND OBSERVATIONS

- SEVERAL COMPLETELY NEW ITEMS RATED VERY HIGHLY
- POTENTIAL FOR OFFERING BERTHING RING WITH REMOTE CONTROLLED POWER, COMMUNICATIONS, AND FLUIDS UMBILICAL CONNECTIONS AS A STANDARD DOCKING MECHANISM
- COMMUNICATE WITH AND CONTROL DOCKED PAYLOADS THROUGH PAYLOAD INTERFACE PANEL

SAIC SPACE SCIENCES

SECOND ARM vs. FSS

Since the second arm and large vehicle docking fixture were not listed separately in the questionnaire, an attempt was made to determine the desirability of a second arm compared to the currently available FSS. Approximately half of the individuals from the original group were contacted and asked to comment on this question. If the issues of a usage fee and the date when a second arm would be available were ignored, then a clear preference was expressed for the second arm. The main reasons for this included the potential for servicing a vehicle outside of the payload bay envelope, the possible elimination of restow requirements for deployed appendages and a possible solution of part of the three body problem (the exchange of very large modules from an equally large support bus).

However, the cost for using this arm and its availability were very large caveats to these answers. If cost and availability are reintroduced into the comparison, then the answers were all variations of "which ever is cheaper to use" when servicing is required. Included in this cost comparison would be not only the usage fee, if any, but the transportation cost and the cost of reserving clearance space in the payload bay when docked to the FSS.

With these considerations in mind, it would appear that the least costly solution would be to use a second RMS since it would satisfy potential customers' desires and minimize NASA's cost to obtain this capability.

SECOND ARM vs FSS

- HPA-TYPE DEVICE NOT BROKEN OUT IN TOOL RATING TABLE
- SELECTED INDIVIDUALS CONTACTED FOR COMPARISON OF SECOND ARM TO FSS
- IGNORING USAGE FEE AND AVAILABILITY ISSUES, SECOND ARM PREFERRED TO FSS
- ATTRACTIVE FEATURES OF SECOND ARM:
 - POTENTIAL FOR SERVICING OUTSIDE PAYLOAD BAY ENVELOPE
 - POSSIBLE ELIMINATION OF RESTOW REQUIREMENTS FOR DEPLOYABLES
 - 3-BODY PROBLEM SOLUTION
- 2ND RMS IS LEAST COSTLY OPTION IN TERMS OF DOLLARS AND PAYLOAD BAY SPACE USAGE

SAIC SPACE SCIENCES

RESPONDENTS RANKING OF GROWTH POSSIBILITIES IN SERVICING

The next several pages will discuss the responses to several of the key questions regarding servicing in general.

The first of these key questions asks the recipients to rank five general types of servicing based on its potential for growth. In this case a 1 indicates the servicing type which has the greatest potential for growth while a 5 indicates the lowest potential. The chart on the facing page summarizes the number of individual responses which ranked a given servicing type on the scale of 1 to 5. Also shown is an averaged ranking over all 12 responses. As can be seen, expendable resupply is ranked the highest at 2.0. This is followed closely by replacement of failed or degraded components at 2.1 and routine payload exchange at 2.3. Sensor upgrades and recovery for return to Earth are seen as least likely to experience significant growth.

RESPONDENTS RANKING OF GROWTH POSSIBILITIES IN SERVICING

	1*	2	3	4	5**	AVG. RATING
EXPENDABLE RESUPPLY	5	3	3	1	0	2.0
ROUTINE PAYLOAD EXCHANGE	4	3	3	2	0	2.3
SENSOR UPGRADES	0	2	3	5	2	3.6
REPLACE FAILED OR DEGRADED COMPONENTS	4	4	3	1	0	2.1
RECOVERY AND RETURN TO EARTH	0	0	0	2	10	4.8

* HIGHEST POTENTIAL GROWTH

** LOWEST POTENTIAL GROWTH

SAIC SPACE SCIENCES

WHO SHOULD LEAD SERVICING DEVELOPMENT?

The questionnaire recipients were asked whether NASA, industry, or some combination of the two should lead in the development of on-orbit servicing hardware. The majority of responses indicated that NASA should lead this effort with minor variations on the level of industry involvement. This group preferred to remain in the role of responding to NASA-developed goals. The exception to this situation are those companies, primarily Fairchild Industries and RCA, who are developing purely commercial spacecraft. This group would prefer to have more direct control over the development and acquisition of the servicing-related hardware needed by their spacecraft.

WHO SHOULD LEAD SERVICING DEVELOPMENT?

- MOST PREFER NASA TAKING THE MAJOR LEADERSHIP ROLE WITH MINOR VARIATIONS ON LEVEL OF INDUSTRY INVOLVEMENT
- EXCEPTIONS ARE THOSE COMPANIES DEVELOPING PURELY COMMERCIAL VENTURES WHO WOULD PREFER TO HAVE MORE CONTROL OVER ESSENTIAL SERVICING HARDWARE

SAIC SPACE SCIENCES

WHO SHOULD LEAD SERVICING OPERATIONS?

In a question related to that on the previous page, the recipients were asked who should lead servicing operations. As can be seen on the facing page, the majority of respondents again indicated that NASA should lead in operations as well as development. Those who felt that industry should lead in hardware development split over who should lead in operations and several who felt that NASA should lead in hardware development were of the opinion that industry should lead operations in one form or another. A comparison of these two questions indicates that development and operations are not necessarily linked by those in the user community, but a majority expect NASA to take the lead in both areas.

WHO SHOULD LEAD SERVICING OPERATIONS?

NUMBER OF RESPONDENTS

• NASA	-	8
• INDUSTRY	-	2
• INDUSTRY WITH JEA OR NASA SUPPORT	-	1
• NASA INITIALLY BUT GRADUALLY TURN OVER TO INDUSTRY	-	1

SAIC SPACE SCIENCES

RELATIVE IMPORTANCE OF PRICING POLICY TO TOOL SET

The final key question regarding general servicing issues asked the recipients to consider the relative importance of a pricing policy to knowledge of tool set specifics. The possible responses to this questions are

- More important (i.e. pricing will decide whether servicing will be done at all)
- Equally important (i.e. servicing will be done but specific design trades cannot be made without pricing information)
- Less important (i.e. servicing must be done regardless of cost and thus having an adequate tool set is most important)

Seventy-five percent of the recipients had an opinion on this matter as can be seen on the facing page. None considered pricing to be less important and a mean response for the remainder lies between equally important and more important. The number and type of responses to this question indicate the degree of concern felt by the user community and the importance assigned to this issue.

RELATIVE IMPORTANCE OF PRICING POLICY TO TOOL SET

• MORE IMPORTANT - 3

← RESPONSE MEAN

• EQUALLY IMPORTANT - 6

• LESS IMPORTANT - 0

• NO RESPONSE - 3

QUESTIONNAIRE SUMMARY - GENERAL IMPRESSIONS

Overall a good response was received from those asked to contribute to this questionnaire considering the fact that all responses were voluntary. The volume of the Air Force response was equally encouraging although details are still unknown at this time.

What is known is that the Air Force currently assumes that an organized effort is underway within NASA for servicing hardware development and that this hardware will be available for DoD missions. On the other hand, commercial contractors are in general waiting for a more organized effort to materialize and assume that NASA will take the leading role in both development and operations of on-orbit servicing. Both of these groups see the greatest potential for growth in the areas of expendable resupply, payload exchange and repair.

One significant note was sounded by those organizations which are closest to flying purely commercial missions. These groups are hesitant to rely on NASA for new hardware which is critical to their particular missions. Reasons cited include unknown costs for hardware usage and uncertain delivery dates due to annual NASA budgetary exercises.

QUESTIONNAIRE SUMMARY - GENERAL IMPRESSIONS

- GOOD RESPONSE FROM THOSE ASKED TO CONTRIBUTE
- AIR FORCE IS ASSUMING NASA HARDWARE WILL BE AVAILABLE FOR DoD MISSIONS
- CONTRACTORS ARE ASSUMING NASA WILL LEAD DEVELOPMENT AND OPERATIONS OF SATELLITE SERVICING
- GREATEST POTENTIAL FOR GROWTH SEEN IN
 - EXPENDABLE RESUPPLY
 - PAYLOAD EXCHANGE
 - REPAIR
- PURELY COMMERCIAL MISSIONS HESITANT TO RELY ON NASA FOR CRITICAL SERVICING HARDWARE

SAIC SPACE SCIENCES

TOOL BOX AND POWER TOOL

Based on the mission model developed previously and on responses obtained from the questionnaire, ten new or modified items were determined to be enabling for future servicing missions. Enabling is defined here to mean one or more identified customers requiring a particular hardware item in order to complete a given servicing mission. The ten hardware items include:

EVA TOOL BOX	BAPS
EVA POWER TOOL	LHe TANKER
REMOTE CONTROLLED FLUID UMBILICAL	RSSS LARGE CRADLE
PAYLOAD INTERFACE PANEL	PAYLOAD HEAT EXCHANGER
5000 LB MONOPROP. TANKER	2nd ARM

Each of these items will be discussed on the following pages along with representative cartoons (when available) of each new or modified concept.

As described in the questionnaire, the tool box is basically a collection of existing EVA hand tools. However, several new tools were suggested which would enhance EVA operations. These include:

"ESSEX WRENCH" - A 3/8" reversible socket wrench with a knob that can be used to turn the square drive

McTETHER - A device which allows sockets, screwdriver tips and various other attachments to be tethered and placed on 3/8" socket wrenches or power tools

3/8" RATCHETING SOCKET WITH SOCKETS AND HOLDER - Wrench and holder designed to hold attachments and ratchet. Allows one handed change of attachments during EVA

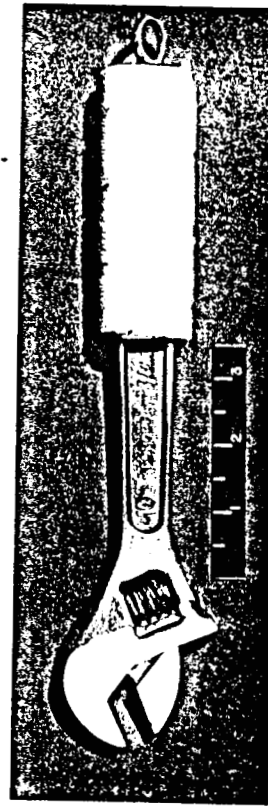
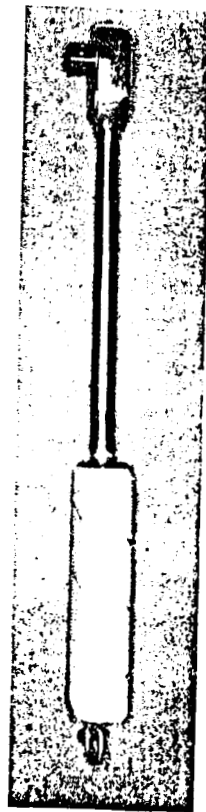
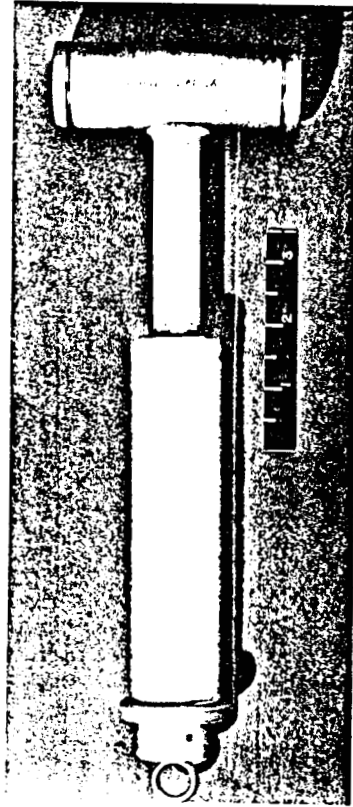
CONNECTOR PIN STRAIGHTENER - Allows straightening of bent connector pins on-orbit

CONNECTOR INSTALLATION TOOLS - Contains the necessary tools for removal and installation of Bendix and Cannon-D connectors.

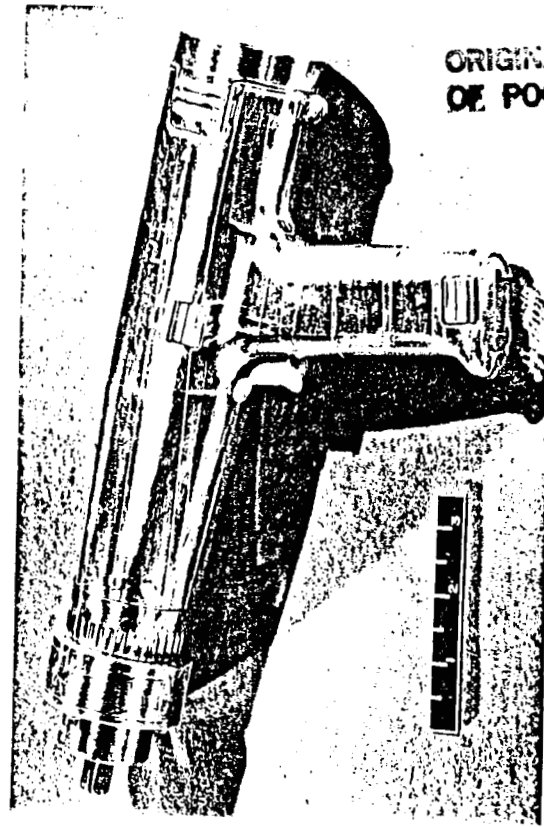
The power tool is a modified version of the existing hand-held power tool and is characterized by the following features:

- Powered by self-contained battery packs
- Adjustable swivel handle
- The tip is a standard 3/8" square adapter. The tip is reversible with a two-speed switch and four stage torque control
- Usable by a selection of bits including sockets, screwdrivers and allen hex keys. A tethering device, such as McTether, would be used to hold these attachments

TOOL BOX AND POWER TOOL



- TOOL BOX WITH VARIOUS EVA HAND TOOLS



ORIGINAL FROM THE
OF POOR QUALITY

- EVA POWER TOOL

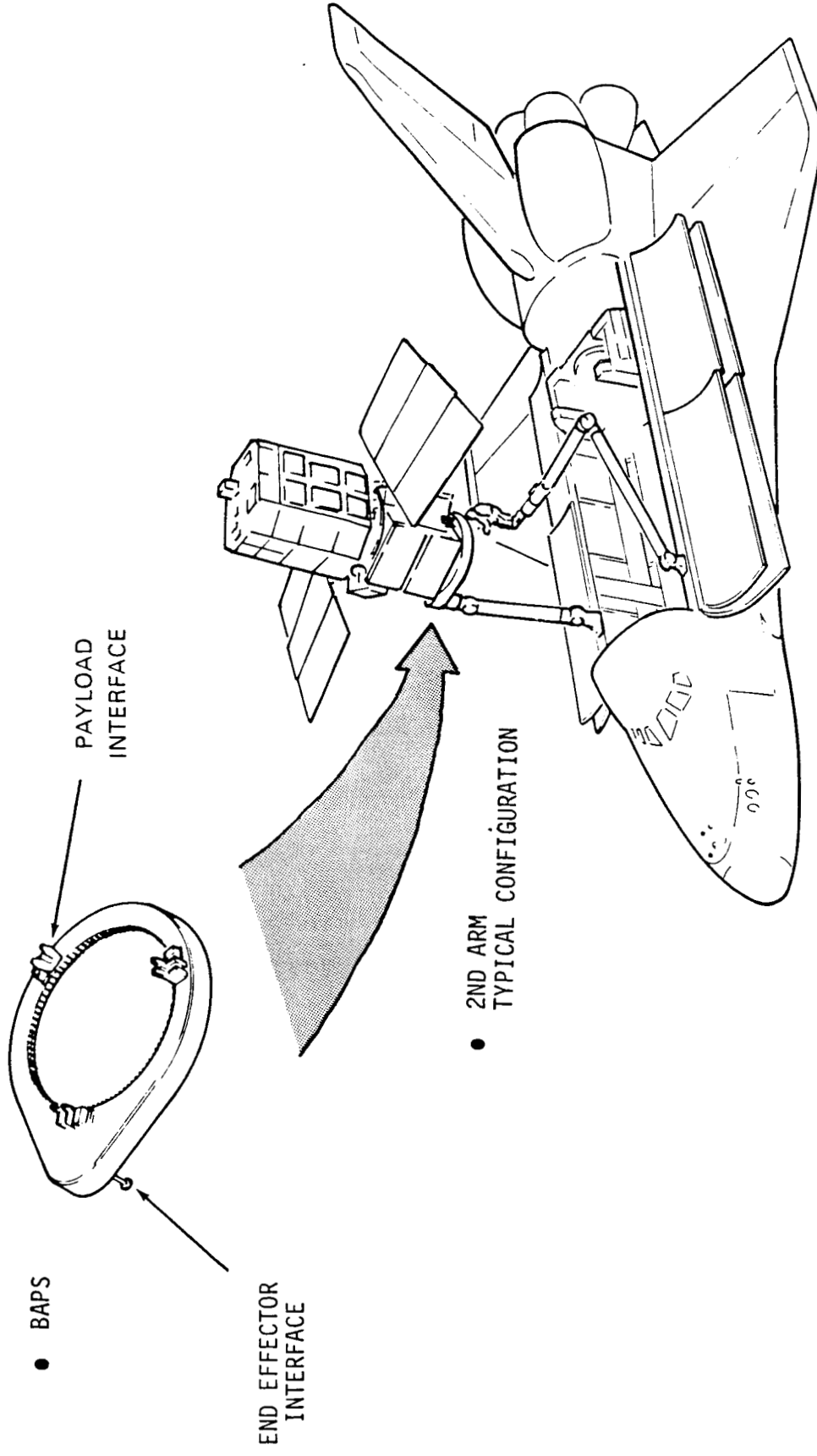
2ND ARM WITH BAPS

As mentioned earlier, a second arm was considered highly desirable by the questionnaire recipients if usage costs and availability issues could be settled. The least expensive option from NASA's point of view would be to acquire a starboard set of manipulator positioning mechanisms (MPMs) and use existing RMS arms on the starboard side of the payload bay. This would provide NASA with a capability which meets the user community desires for servicing outside of the cargo bay envelope and minimal usage of cargo bay space for docking hardware.

To meet existing and future berthing needs, a docking ring similar to that used on the FSS would be required. Modifications would be necessary to make the device compatible with the RMS end effector. Such a concept has already undergone preliminary study and can provide, at a minimum, both power and communication connections with the docked payload.

(Drawings provided by SPAR Aerospace)

2ND ARM WITH BAPS



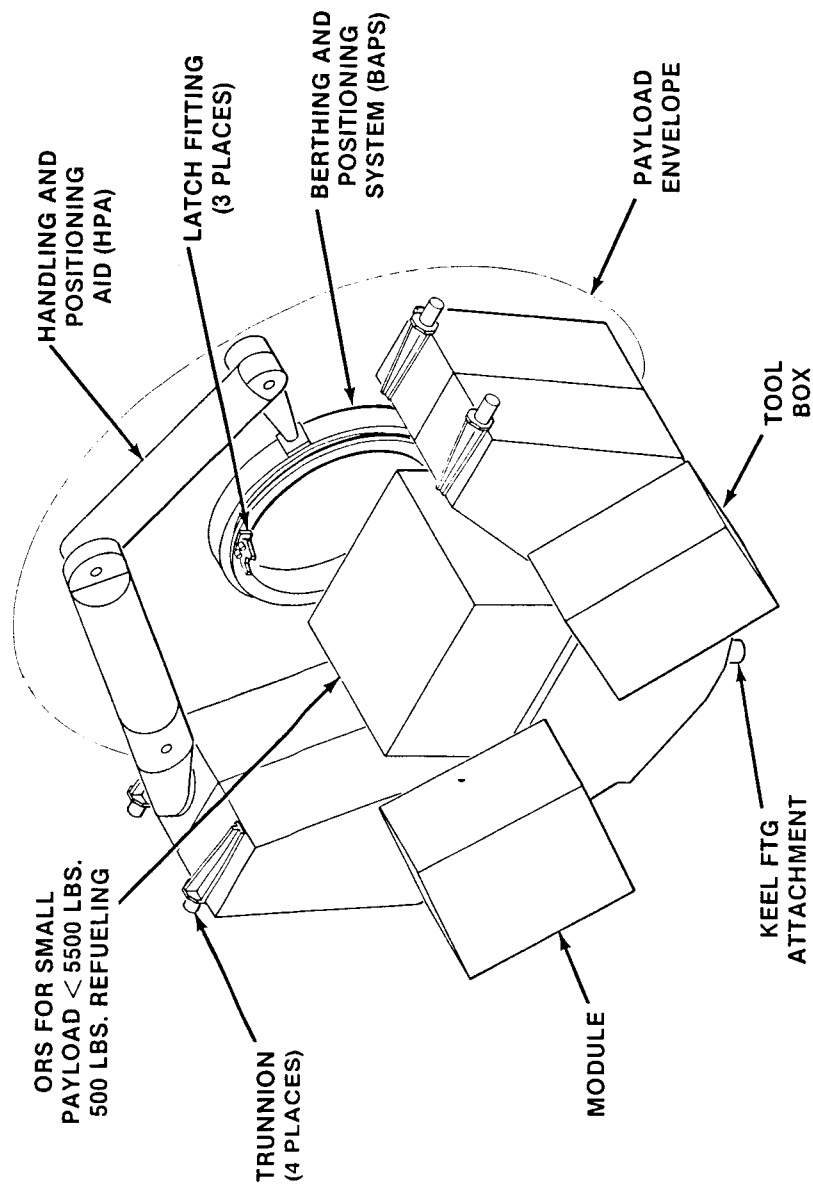
RSSS SMALL CRADLE WITH 2ND ARM

An alternative to the second RMS would be to mount an HPA-type arm on a small cradle (approximately four feet wide) which would then be mounted in the payload bay. The arm itself is approximately 20 feet long when fully extended and has three joints which provides five degree-of-freedom motion. Each joint can be rigidized by a driven tooth clamp to support payloads during Orbiter primary reaction control system (PRCS) thrusting. The arm will be mechanically stiffer than the RMS and will be capable of supporting either a standard end effector or the BAPS docking ring (as depicted on the facing page). The cradle will be capable of supporting approximately 4,000 lb of additional equipment such as replacement modules, tool boxes and/or the Orbital Refueling System.

(Concept and figure provided by Fairchild Industries)

RSSS SMALL CRADLE WITH 2ND ARM

RECONFIGURABLE SATELLITE SERVICE SYSTEM
SMALL SPACECRAFT < 5500 LBS.

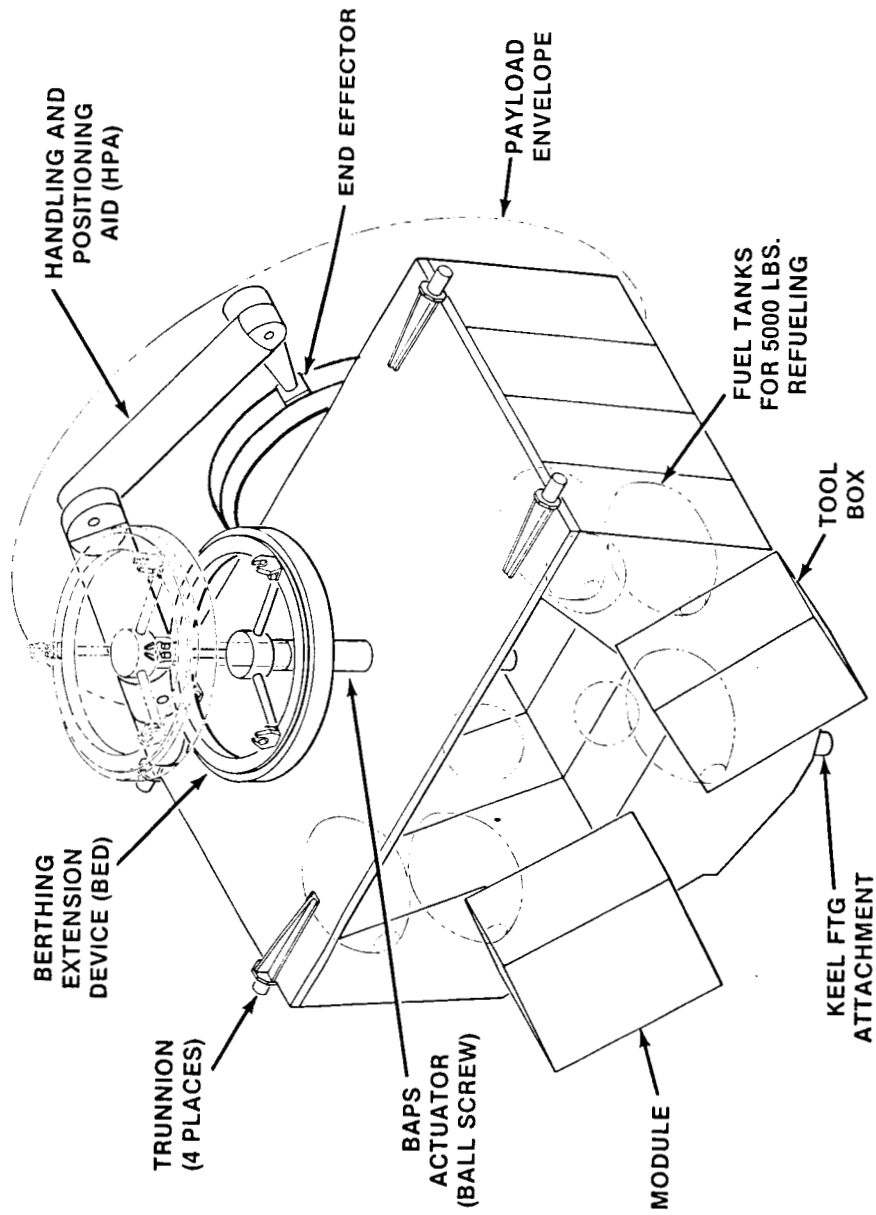


RSSS COMBINED SYSTEM

In order to support the servicing of large spacecraft (such as in the three body problem) the RSSS small cradle can be expanded to approximately eight feet in length and adds a berthing device capable of supporting payloads of 30,000-40,000 lbs during PRCS firings. This berthing device would have a single degree-of-freedom to allow a BAPS docking ring to be stowed during launch and deployed above the payload bay envelope during on-orbit operations. The cradle would be capable of supporting approximately 8,000 lb of additional equipment including replacement modules, tool boxes and fuel tanks for up to 5,000 lb of propellant.

(Concept and figure provided by Fairchild Industries)

RECONFIGURABLE SATELLITE SERVICING SYSTEM LARGE SPACECRAFT



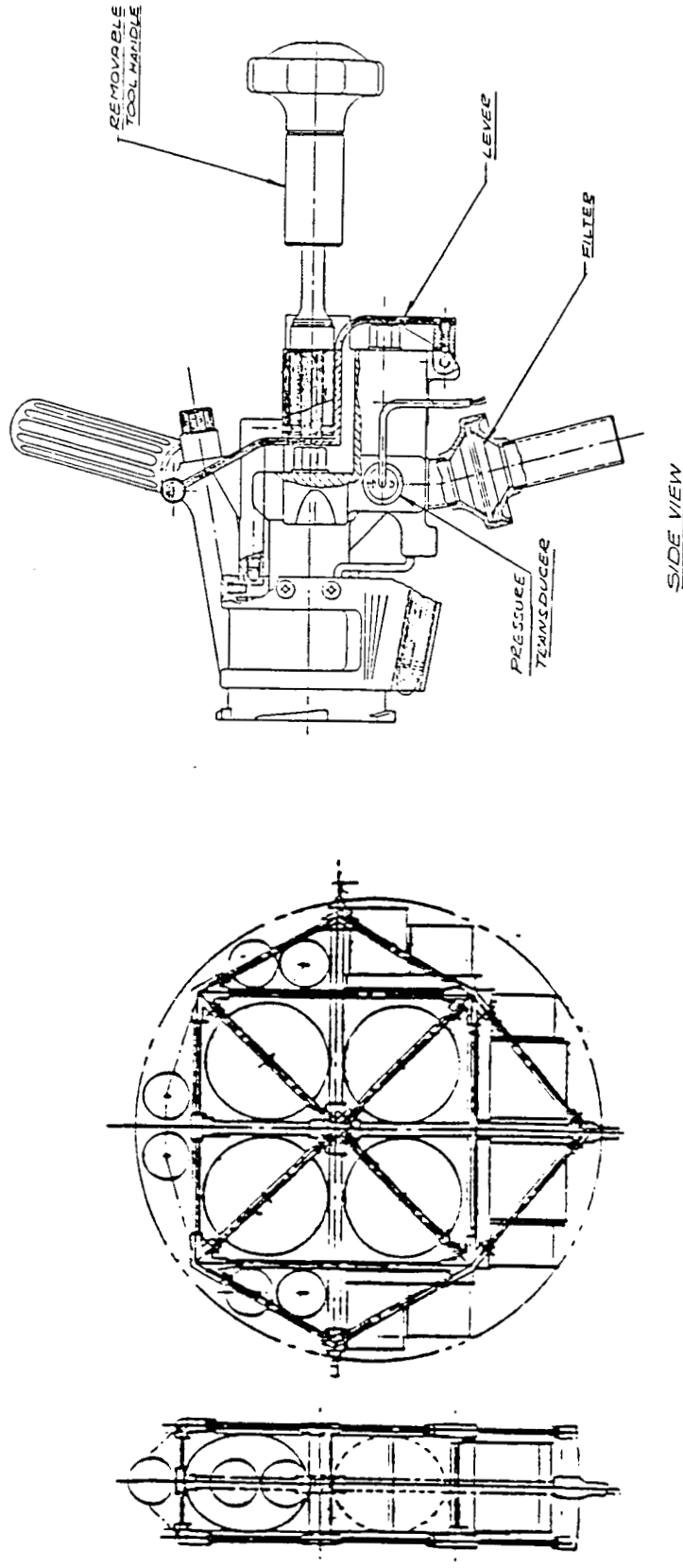
LARGE TANKER AND FLUIDS COUPLING

Of the three large tanker concepts (monopropellant, bipropellant and liquid cryogen) listed in the questionnaire, only the 5,000 lb monopropellant tanker was rated very highly. In addition, no missions were identified which would utilize bipropellants or liquid cryogens in the time frame under consideration. Thus, only the monopropellant tanker was carried as a high priority hardware item.

The questionnaire results also indicated that a remote controlled fluids coupling should be used with this tanker. At present a manually operated fluids coupling is under development for use with the GRO spacecraft, but it is assumed that an automated coupling could be derived from this device.

(Tanker drawing provided by Grumman, Fluids Coupling drawing provided by Fairchild Industries)

LARGE TANKER AND FLUIDS COUPLING



TANKER CONCEPT

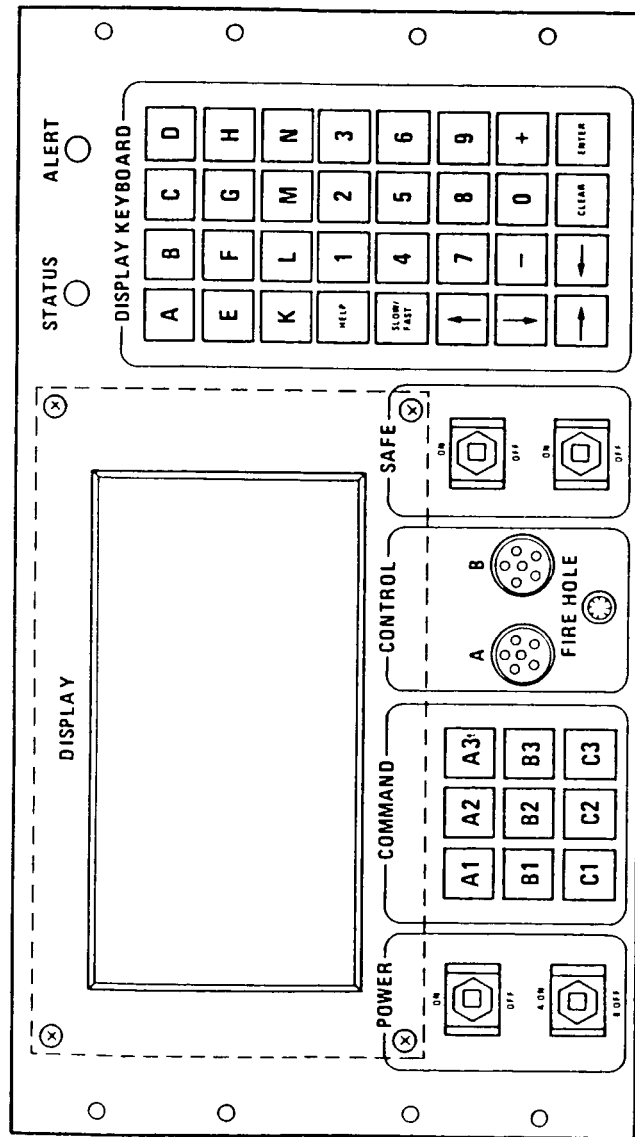
FLUIDS COUPLING (EVA VERSION)

PAYLOAD INTERFACE PANEL

The Payload Interface Panel provides a man/machine interface to control and monitor payloads from the aft flight deck of the Shuttle Orbiter. This panel consists of a payload display and control module with data processing and communication capabilities. The functional capability thus includes command, display, telemetry control, and other payload-unique features while remaining independent of the Shuttle Orbiter's General Purpose Computers (GPC). This panel will be used in association with the standard electrical power/communication umbilical located on the BAPS docking ring and the remote controlled fluids umbilical.

(This drawing taken from "Satellite Services Catalog" JSC-19211)

PAYLOAD INTERFACE PANEL



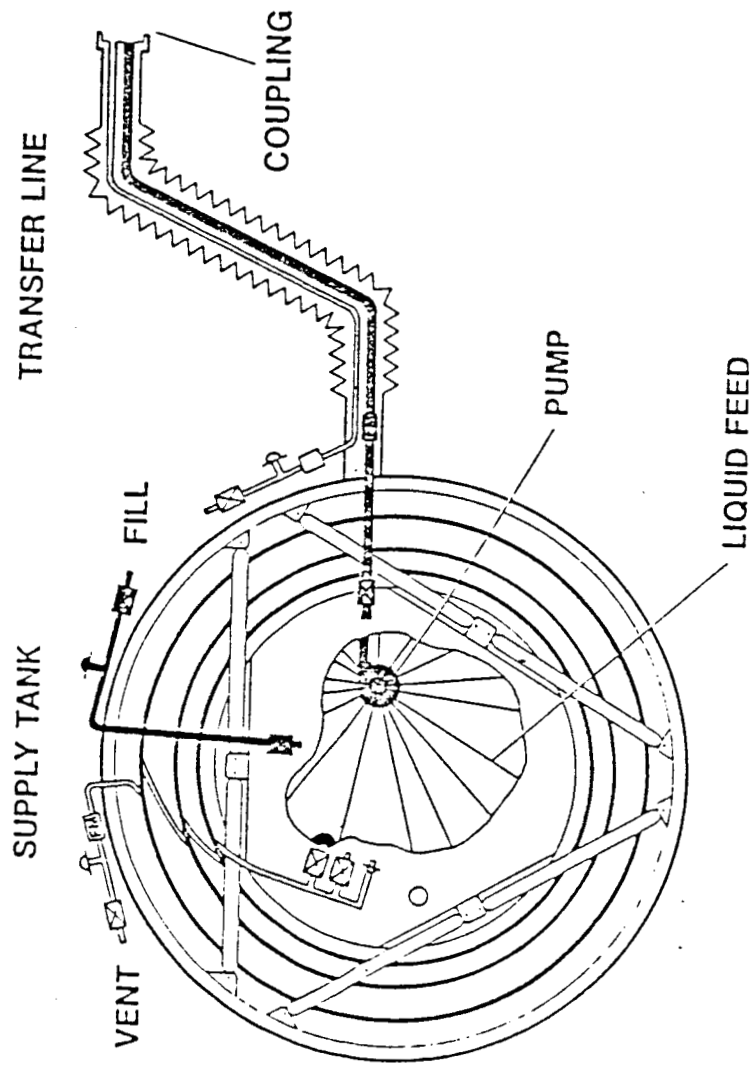
LHe TANKER AND PAYLOAD HEAT EXCHANGER

The Liquid Helium Tanker will have a capacity for 500 lb of superfluid helium. The system will contain all necessary avionics and thermal protection subsystems to maintain the helium in its superfluid state during launch, rendezvous and fluid transfer to the payload. A special purpose coupling will also be required to allow the transfer of this fluid.

The Payload Heat Exchanger provides an on-orbit fluid loop cooling system for payloads berthed in the cargo bay. This system provides the necessary fluid pumps and mechanical interfaces to connect the payload to the Shuttle Orbiter's cooling system. As such, this heat exchanger will be able to remove 10,750 BTU/hr or 14,500 BTU/hr with radiator kits. The fluid pump subsystem of this heat exchanger would be derived from those already in use by Spacelab.

(Tanker drawing provided by NASA/Ames Research Center)

LHe TANKER AND PAYLOAD HEAT EXCHANGER



NOTE: HEAT EXCHANGER
NOT SHOWN

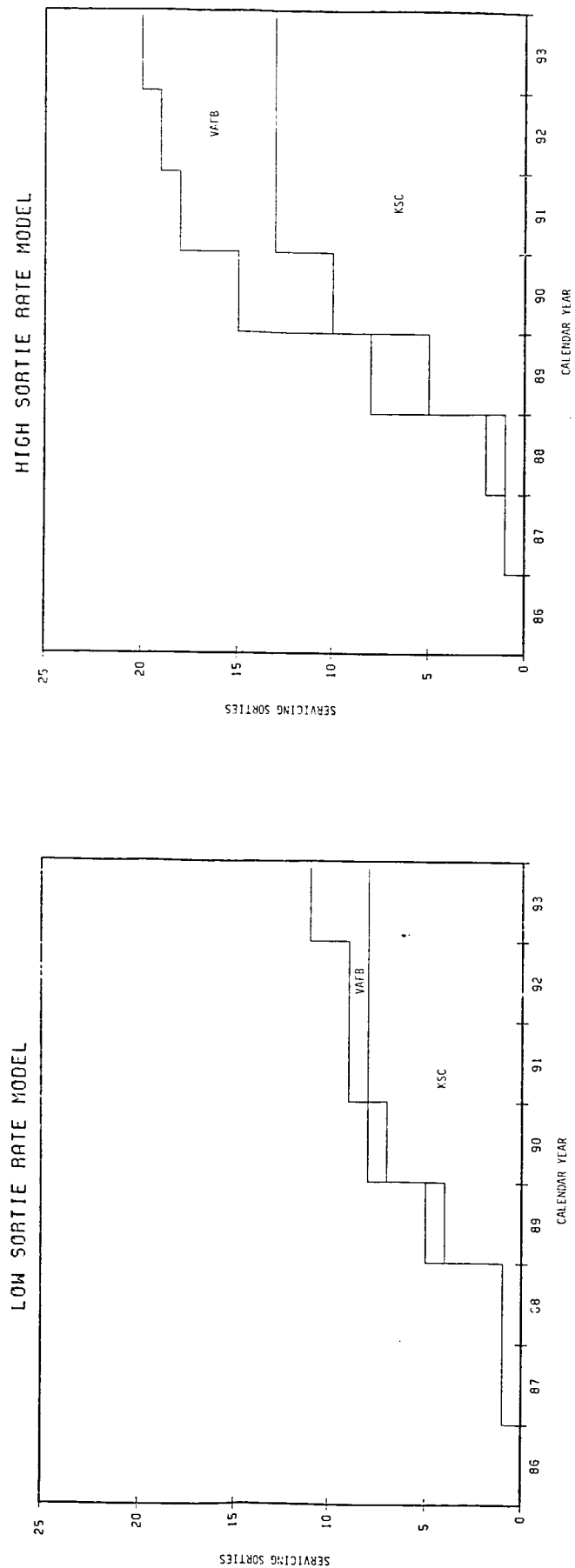
- LIQUID HELIUM TANKER

ON-ORBIT SERVICING SORTIE RATE

The table below and the figures on the facing page illustrate lower and upper limits to the servicing sortie rate based on information obtained from the mission model and contacts with the user community. The potential traffic volume even in the low model indicates that multiple flight articles will be needed for each of the major hardware items.

	87	88	89	90	91	92	93
	KSC VAFB	KSC VAFB	KSC VAFB	KSC VAFB	KSC VAFB	KSC VAFB	KSC VAFB
LOW MODEL							
NASA			1	2	2	2	1 2
COMMERCIAL			2	2	4	4	4
DoD				1		1	
FOREIGN		1	1	2	2	2	2
CONTINGENCY	1		1	1	1		1 1
TOTAL	1 0	1 0	4 1	7 1	8 1	8 1	8 3
HIGH MODEL							
NASA			1	2	2	2	1 2
COMMERCIAL			2	5	7	8	8
DoD				4	4	5	4
FOREIGN		1	1	3	3	3	3
CONTINGENCY	1	1	1 1	1	1 1	1	1 1
TOTAL	1 0	1 1	5 3	10 5	13 5	13 6	13 7

ON-ORBIT SERVICING SORTIE RATE



DEVELOPMENT PLAN OPTIONS

Information gathered up to this point is sufficient to allow cost estimates to be made for each of the high priority tool items. However, the lack of definite hardware requirements or servicing dates within the user community argues against using this cost data in a single comprehensive development plan.

As an alternate course of action it was decided to bound the plan possibilities with respect to both cost and schedule limitations. Thus, three scenarios were postulated: a low cost, long schedule plan; a high cost, short schedule plan and an intermediate plan. In each case two flight articles for each hardware item were assumed and only hardware costs were estimated. Other costs such as software development and crew training were not included.

The next several pages will provide additional details for each of the three scenarios.

DEVELOPMENT PLAN OPTIONS

- LACK OF FIRM REQUIREMENTS ARGUES AGAINST A SINGLE, COMPREHENSIVE DEVELOPMENT PLAN
- BOUND PROBLEM WITH LOW, HIGH AND INTERMEDIATE DEVELOPMENT SCENARIOS
- ASSUME TWO FLIGHT ARTICLES FOR EACH HARDWARE ITEM
- THREE POSSIBLE SCENARIOS
 - NASA-ONLY PROGRAM (SCENARIO 1)
 - FAST START PROGRAM TO MEET ANTICIPATED COMMERCIAL NEEDS (SCENARIO 2)
 - POSSIBLE COMPROMISE - MAINTAIN ULTIMATE CAPABILITY OF FAST START BUT STRETCH OUT TO ADAPT TO EXISTING NASA SCHEDULE (SCENARIO 3)

SCENARIO 1: NASA-ONLY SERVICING

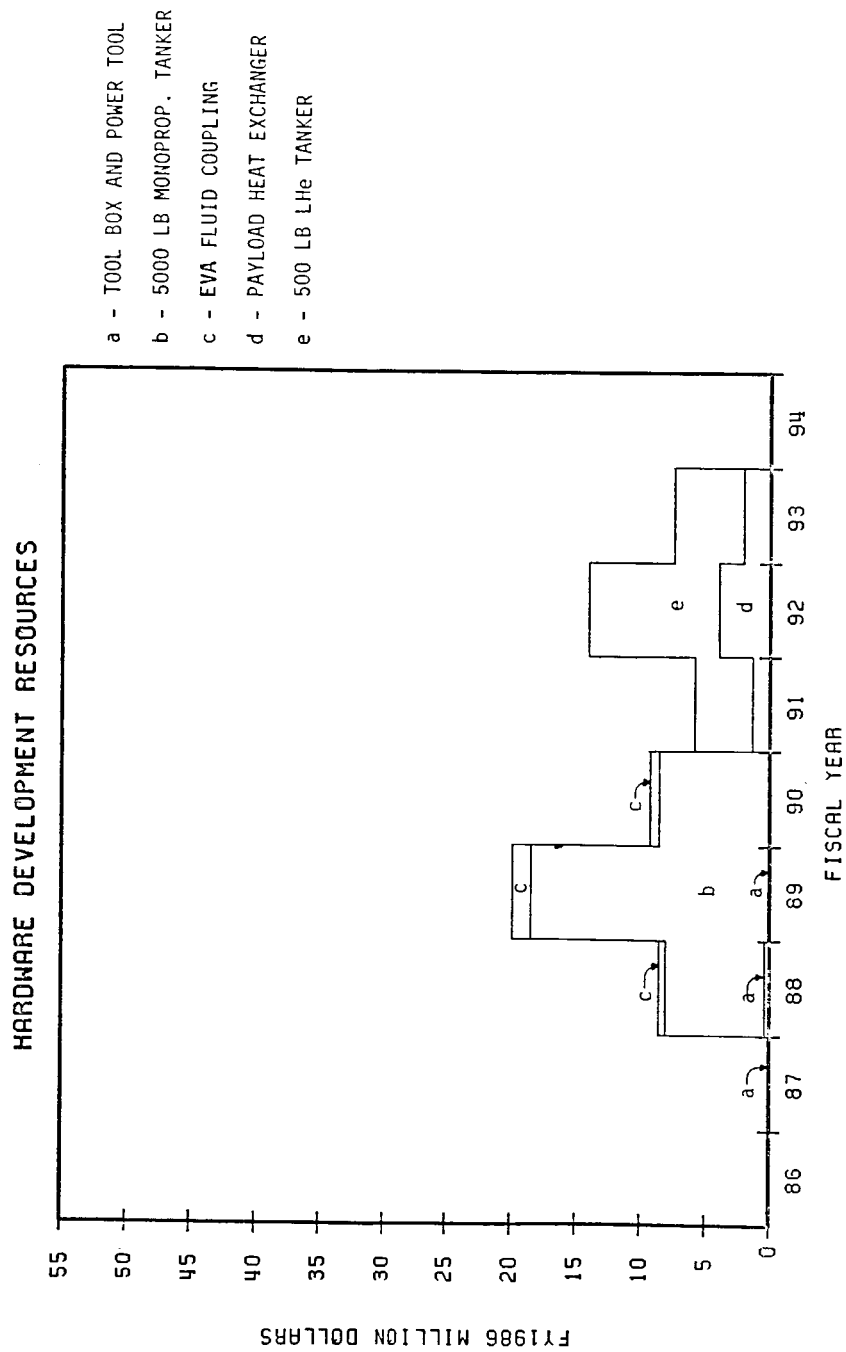
The first scenario considers only those hardware items for which NASA currently has a need and paces the development based on NASA's schedule. With this assumption the following hardware elements were included in the development plan.

- TOOL BOX AND POWER TOOL (combined into one cost element)
- 5000 LB MONOPROPELLANT TANKER
- EVA FLUID COUPLING
- PAYLOAD HEAT EXCHANGER
- 500 LB LHe TANKER

These hardware items are estimated to have a total cost of \$65M (FY86) spread over seven years. The peak year funding is estimated to reach \$20M (FY86) in Fiscal Year 1989.

With these assumptions this scenario represents a baseline case against which other scenarios can be compared.

SCENARIO 1: NASA - ONLY SERVICING



SCENARIO 1: ADVANTAGES AND DISADVANTAGES

The main advantage of this scenario lies in the fact that all foreseeable NASA servicing requirements are met based on NASA's current schedule. This also represents the lowest overall hardware development cost based on the assumption that NASA will support its own servicing needs. Any other development plan will build from this level.

The disadvantage of this scenario is the fact that it does not meet all of the anticipated needs in the non-NASA user community. In addition, those hardware needs which are fulfilled typically do not meet the anticipated schedule.

SCENARIO 1: ADVANTAGES AND DISADVANTAGES

- ADVANTAGES

- MEETS ALL FORESEEABLE NASA REQUIREMENTS AND SCHEDULES
- LOWEST PROGRAM COST

- DISADVANTAGES/RISKS

- DOES NOT MEET ALL USER COMMUNITY NEEDS OR SCHEDULES

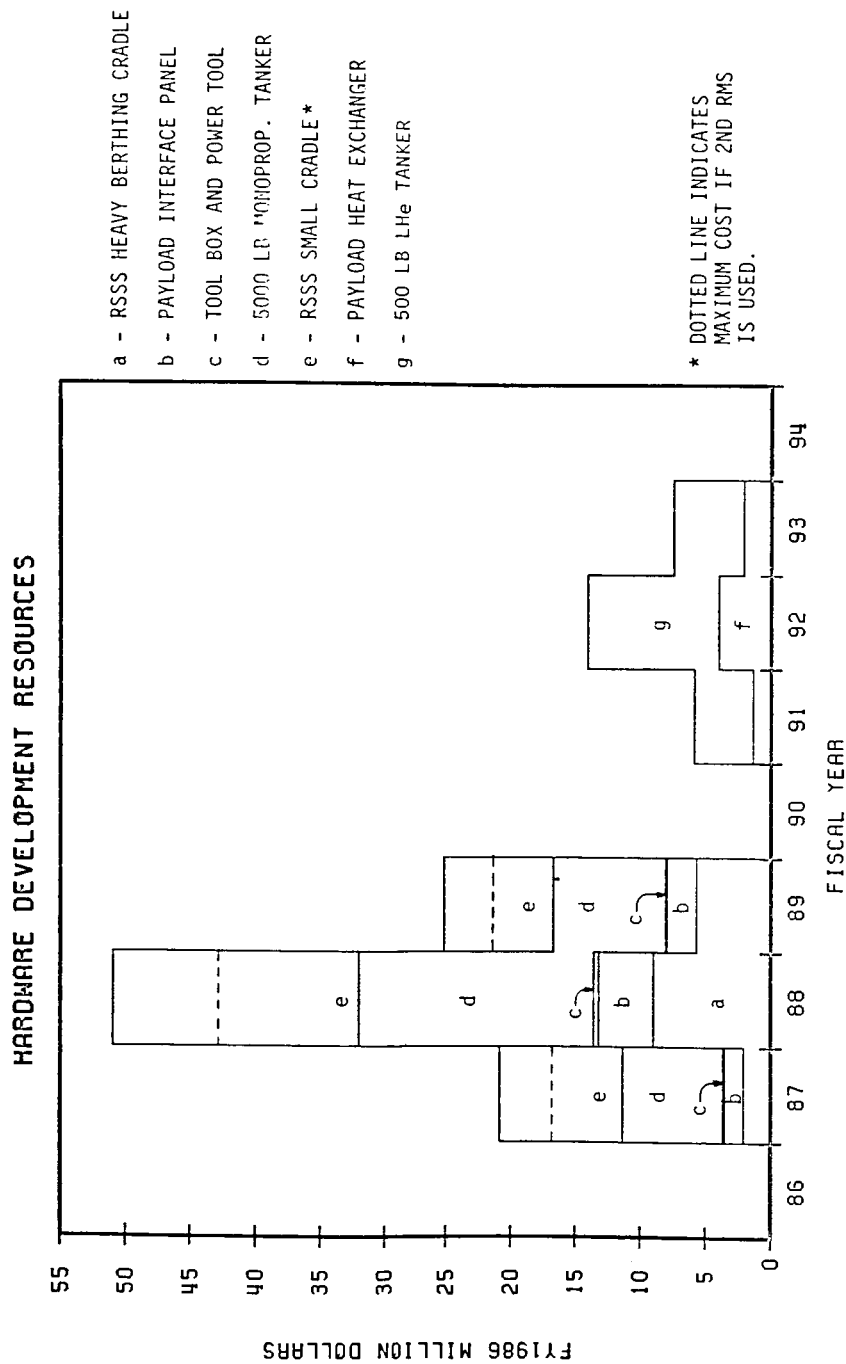
SCENARIO 2: FAST START FOR ALL USERS

The second scenario attempts to meet all hardware needs of all customers based on the current best estimate of when these items will be needed. As such, this scenario is driven by commercial materials processing spacecraft the first of which is anticipated to be operational in the second or third quarter of 1989. To meet the needs of these vehicles the following hardware elements were included in this plan

- RSSS HEAVY BERTHING CRADLE
- 2ND RMS WITH BAPS (IN LIEU OF RSSS SMALL CRADLE)
- PAYLOAD INTERFACE PANEL
- PAYLOAD HEAT EXCHANGER
- TOOL BOX AND POWER TOOL
- 500 LB LHe TANKER
- 5000 LB MONOPROPELLANT TANKER
- REMOTE CONTROLLED FLUID UMBILICAL (INCLUDED WITH RSSS OR 2ND RMS BAPS)
- RSSS SMALL CRADLE WITH HPA

These hardware items are estimated to have a total cost of \$125M (FY86) again spread over seven years. The peak year funding for this plan is estimated to be \$51M (FY86) in Fiscal Year 1988 and represents roughly 40 percent of the total cost of this plan. In addition, a trade-off was considered which involved the second RMS and the RSSS small cradle. If a BAPS is developed such that the second RMS can provide the same berthing capability as the small cradle, then an overall savings of \$16M (FY86) can be realized.

SCENARIO 2: FAST START FOR ALL USERS



SCENARIO 2: ADVANTAGES AND DISADVANTAGES

The obvious advantage of this plan is that it meets all of the anticipated hardware needs of the customers and does so based on that community's schedule.

The disadvantages of this plan begin with the very high start-up cost to develop the required capabilities. This fast start-up will require two NASA programs (the 5,000 lb Tanker and the Fluid Coupling) to be accelerated in order to meet the given schedule. However, this schedule itself represents something of a risk since it is the current best estimate for these commercial spacecraft and difficulties unrelated to servicing may delay the first servicing date.

SCENARIO 2: ADVANTAGES AND DISADVANTAGES

- ADVANTAGES

- MEETS ALL FORESEEABLE CUSTOMER NEEDS AND SCHEDULES

- DISADVANTAGES/RISKS

- VERY HIGH START-UP COST
- ACCELERATES TWO NASA PROGRAMS (5000 LB TANKER & FLUID COUPLING)
- RELIES ON CUSTOMER ESTIMATES FOR FIRST USE DATE

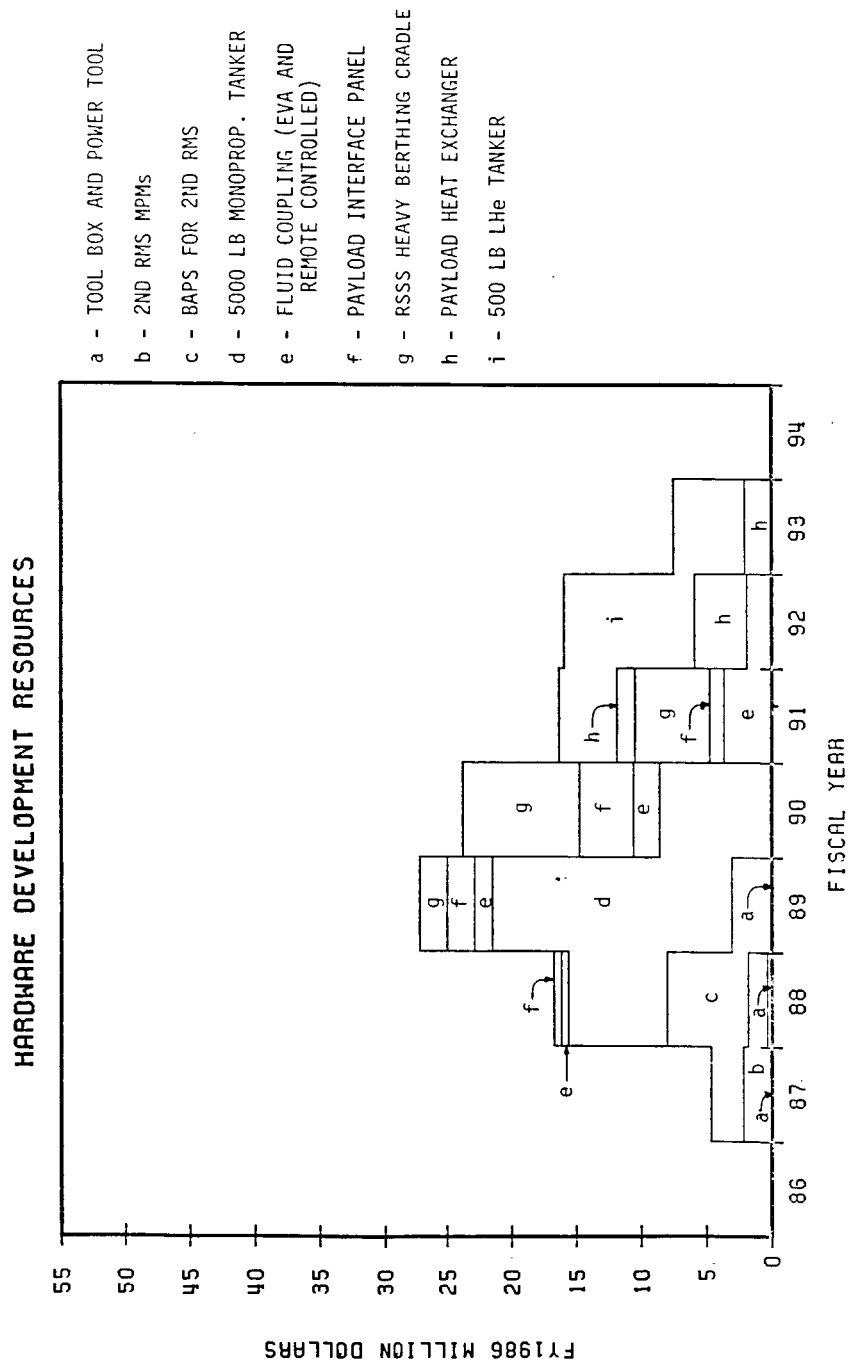
SCENARIO 3: COMPROMISED START WITH SAME DELAYS

The last scenario considers a possible compromise between the first two limiting cases. In this scenario, the same ultimate capabilities found in the second scenario would be maintained but development phasing would more closely follow the schedule of the first scenario. With these assumptions the following hardware elements were included in the development plan

- TOOL BOX AND POWER TOOL • PAYLOAD INTERFACE PANEL
- 2ND RMS MPMS • RSSS HEAVY BERTHING CRADLE
- BAPS FOR 2ND RMS • PAYLOAD HEAT EXCHANGER
- 5000 LB MONOPROPELLANT TANKER • 500 LB LHe TANKER
- FLUID COUPLING (EVA VERSION
FOLLOWED BY REMOTE CONTROLLED)

Using the lower cost of a second RMS instead of the RSSS small cradle results in a total cost of \$112M (FY86) spread over the seven years of the plan. The peak year funding is estimated to reach \$27M (FY86) in Fiscal Year 1989.

SCENARIO 3: COMPROMISED START WITH SOME DELAYS



SCENARIO 3: ADVANTAGES AND DISADVANTAGES

The major advantages of this plan lie in the fact that all anticipated customer needs are met in a manner which more closely parallels NASA's current schedule. This results in a peak program cost that is approximately half of that found in Scenario 2 and not much higher than that of Scenario 1. The plan is also phased to build from a capability to service smaller, simpler spacecraft up to a more robust capability which can meet the more sophisticated needs of larger spacecraft seen in the later years of this plan.

The largest disadvantage of this plan is that it does not completely meet the anticipated schedule of the entire user community. In point of fact, this plan would defer complete servicing support of the materials processing missions by two years.

SCENARIO 3: ADVANTAGES AND DISADVANTAGES

- ADVANTAGES

- MEETS FORESEEABLE CUSTOMER NEEDS
- PEAK PROGRAM COSTS APPROXIMATELY HALF THOSE IN SCENARIO 2
- HARDWARE ITEMS PHASED FOR ORDERLY BUILDUP OF CAPABILITIES
- MEETS NASA SCHEDULE

- DISADVANTAGES/RISKS

- DOES NOT COMPLETELY MEET USER COMMUNITY SCHEDULE; DEFERS COMPLETE SERVICING SUPPORT OF MATERIALS PROCESSING MISSIONS FOR APPROXIMATELY 2 YEARS

SUMMARY OF PRESENT SITUATION

With the preceding pages providing the necessary background information, the present situation of on-orbit satellite servicing can be summarized as follows. By the year 1989 or 1990 there will probably be one or more non-NASA spacecraft in low altitude orbits which will require regularly scheduled servicing. It is assumed that the Space Shuttle Orbiter will be the vehicle which will perform the servicing, but the exact means by which this servicing will be accomplished is uncertain. One problem contributing to this uncertainty is the lack of a focal point for on-orbit servicing within the government or industry. While NASA would be the obvious agency to serve as this focal point, there is little perceived movement towards this conclusion. If there is no change in the status quo then potential servicing customers will opt to minimize their dependence on NASA and proceed with the design of unique servicing hardware, probably on an ad hoc, uncoordinated basis. At present, NASA is not in a position to quickly react to this situation.

SUMMARY OF PRESENT SITUATION

- NON-NASA SPACECRAFT REQUIRING ROUTINE SERVICING ARE LIKELY IN 1989-1990 TIME FRAME
- SERVICING EFFORTS NOT FOCUSED EITHER WITHIN GOVERNMENT OR INDUSTRY
- IF NASA MAINTAINS STATUS QUO (NO COMMITMENT TO SERVICE NON-NASA PAYLOAD, NO PRICING POLICY)
 - CUSTOMERS WILL TRY TO MINIMIZE NASA INVOLVEMENT
 - CUSTOMERS WILL DESIGN UNIQUE SERVICING HARDWARE ON AD HOC, UNCOORDINATED BASIS
- NASA NOT CURRENTLY IN POSITION TO DO MAJOR ROUTINE SERVICING OF FIRST WAVE OF NON-NASA SERVICEABLE SPACECRAFT

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STUDY RECOMMENDATIONS

Based on the information gathered from potential customers and data generated as part of this study, the following course of action is recommended.

- (1) NASA should formally commit to routine on-orbit servicing of non-NASA spacecraft as a standard feature of the STS. Potential customers already expect NASA to do this, but are waiting for a formal announcement. As part of the this commitment, a focal point within NASA must be identified to be cognizant of servicing related activities within NASA and to serve as a point of contract for non-NASA customers.
- (2) A set of generic servicing equipment should be baselined with their capabilities made known to the potential customers. These customers will not design their vehicles for a particular type of servicing if there is a risk that the necessary equipment will not be available at the appropriate time. The user community survey indicated that five hardware items are of particular interest to this community. These items include a payload interface panel, a second arm, a monopropellant tanker with at least 5000 lb. capacity, a remote controlled fluids coupling, and a heavy berthing/docking fixture. This equipment should be available from all Shuttle Orbiters to avoid manifesting limitations. As servicing expands beyond the Shuttle Orbiter, equipment features should be the same wherever possible for servicing done by an OMV, OTV or the Space Station. Customers will then not be forced to select the servicing vehicle when their spacecraft is designed.

STUDY RECOMMENDATIONS

RECOMMENDED COURSE OF ACTION BASED ON CUSTOMERS' INPUTS

(1) COMMIT NASA TO ROUTINE SERVICING FOR NON-NASA SPACECRAFT

- IDENTIFY AGENCY FOCAL POINT FOR SERVICING RESPONSIBILITY

(2) BASELINE GENERIC SERVICING EQUIPMENT

- CUSTOMER WILL NOT DESIGN FOR SERVICING AT RISK OF NOT HAVING EQUIPMENT AVAILABLE
- PRIORITIZE AND COMMIT TO DEVELOPMENT OF HIGHLY DESIRABLE HARDWARE INCLUDING: TANKER, 2ND RMS OR HPA, HEAVY BERTHING AND DOCKING FIXTURE, REMOTE CONTROLLED FLUIDS UMBILICAL, AND PAYLOAD INTERFACE PANEL
- EQUIPMENT FEATURES SHOULD BE THE SAME (IF POSSIBLE) FOR SERVICING HARDWARE USED BY THE STS, SPACE STATION, OMV AND OTV

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STUDY RECOMMENDATIONS (continued)

- (3) With a set of baselined servicing equipment in place, the potential customers must be given a set of cost guidelines for the use of this equipment and for any other non-hardware related items which must be paid for (i.e. transportation to orbit, training, etc). As indicated by the questionnaire, the user community places equal or greater value on this information than on hardware details since cost trades must be performed early in the design cycle.
- (4) One of the results from the questionnaire was the perception by the user community that NASA would lead both hardware development and on-orbit operations. The DoD is also assuming that a hardware development program is underway within NASA and that this hardware will be available when the DoD decides the type and volume of servicing its wishes to carry out. These two perceptions indicate that a dialog between NASA and the non-NASA community must be opened to avoid misconceptions and to allow for appropriate planning by all involved. The needs and roles of all organizations who will eventually be involved with on-orbit servicing are currently in a dynamic state and will remain so for the next several years. A regularly scheduled forum where needs, desires and constraints can be aired will help each organization to define its own options and may allow for cooperative endeavors to be arranged.
- (5) Finally, interfaces for servicing equipment must be standardized. The customer will need this kind of information to properly design their spacecraft for compatibility. Standardization will allow the customer to use the same automated or remotely operated equipment regardless of orbit location (LEO, polar, GEO, etc.) or servicing vehicle (Shuttle Orbiter, OMV, OTV, or Space Station). The details of these interface standards is one of the tasks which could be worked out by the government/industry forums suggested in item (4).

STUDY RECOMMENDATIONS (CONCLUDED)

- (3) ESTABLISH SERVICING COST OR PRICING GROUND RULES
 - CUSTOMERS REQUIRE THIS INFORMATION NOW FOR TRADE STUDIES
- (4) BEGIN GOVERNMENT/INDUSTRY SERVICING MEETINGS
 - NEEDS AND ROLES OF VARIOUS ORGANIZATIONS ARE IN A DYNAMIC STATE AND WILL REMAIN SO FOR NEXT SEVERAL YEARS
 - MAINTAIN FLOW OF INFORMATION REGARDING DESIRES, REQUIREMENTS AND CONSTRAINTS
- (5) STANDARDIZE SERVICING INTERFACES
 - CUSTOMERS NEED GUIDELINES TO DESIGN FOR SERVICING AND BE COMPATIBLE WITH SERVICING EQUIPMENT
 - AUTOMATED OR REMOTELY OPERATED INTERFACES SHOULD BE SAME FOR ALL SERVICEABLE SPACECRAFT: LEO, POLAR, GEO, ETC.
 - DETAILS CAN BE WORKED OUT IN GOVERNMENT/INDUSTRY SERVICING MEETINGS TO SATISFY LARGEST POSSIBLE USER GROUP

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